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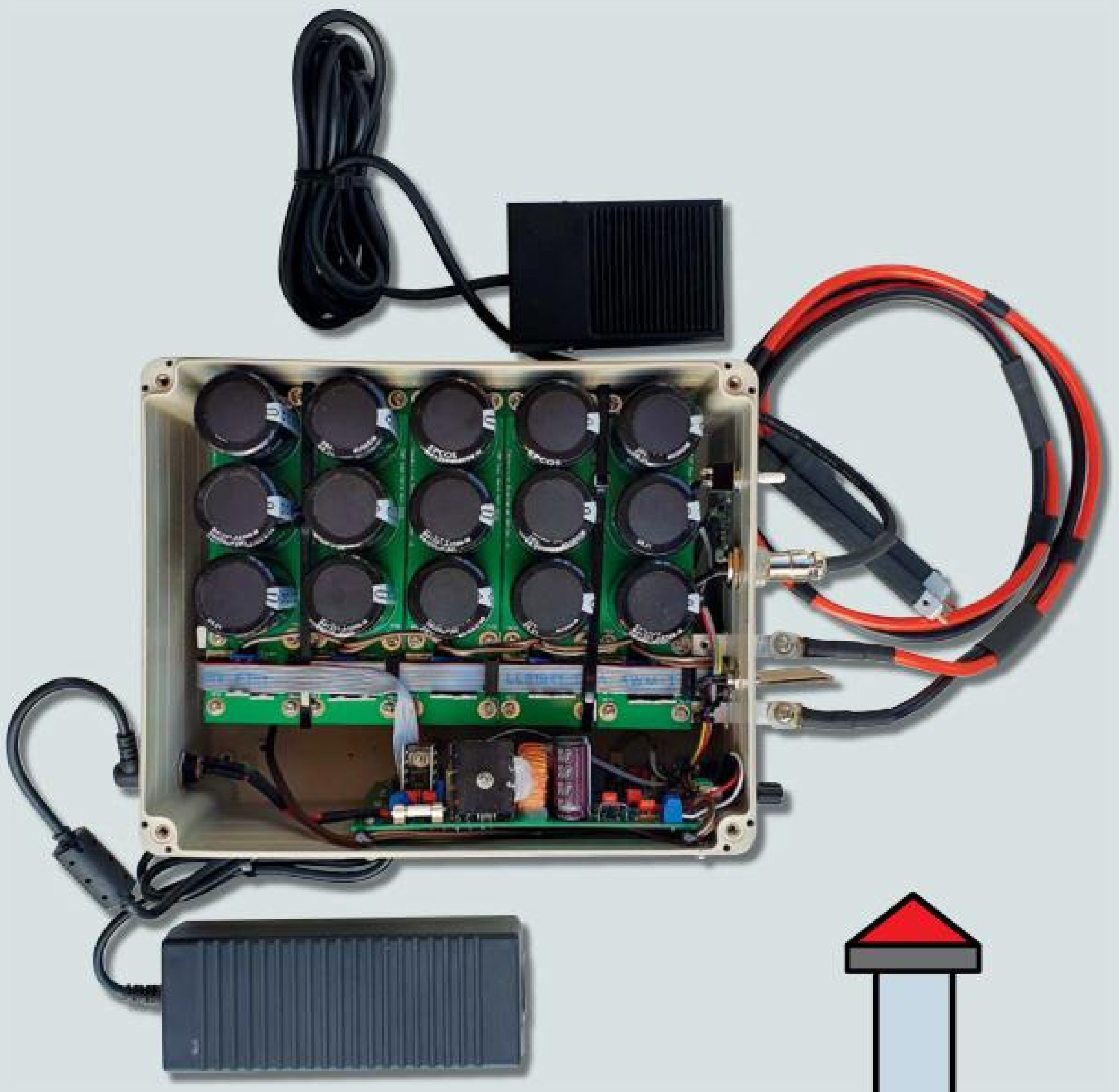

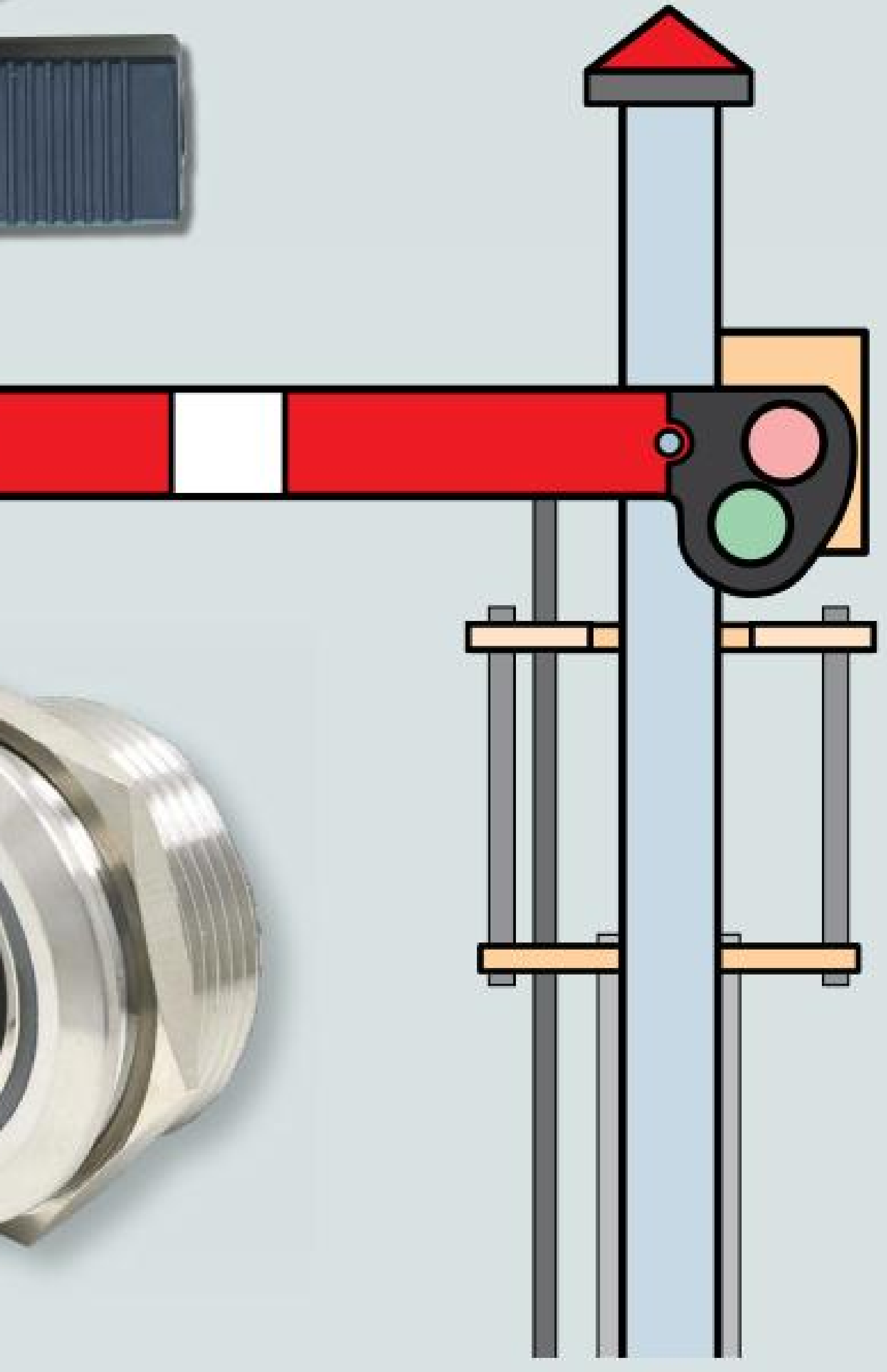

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The April 2023 issue of *Practical Electronics* will be published on Thursday, 2 March 2023 – see page 72.

WIRELESS FOR THE WARRIOR

by LOUIS MEULSTEE

THE DEFINITIVE TECHNICAL HISTORY OF RADIO COMMUNICATION EQUIPMENT IN THE BRITISH ARMY

The *Wireless for the Warrior* books are a source of reference for the history and development of radio communication equipment used by the British Army from the very early days of wireless up to the 1960s.

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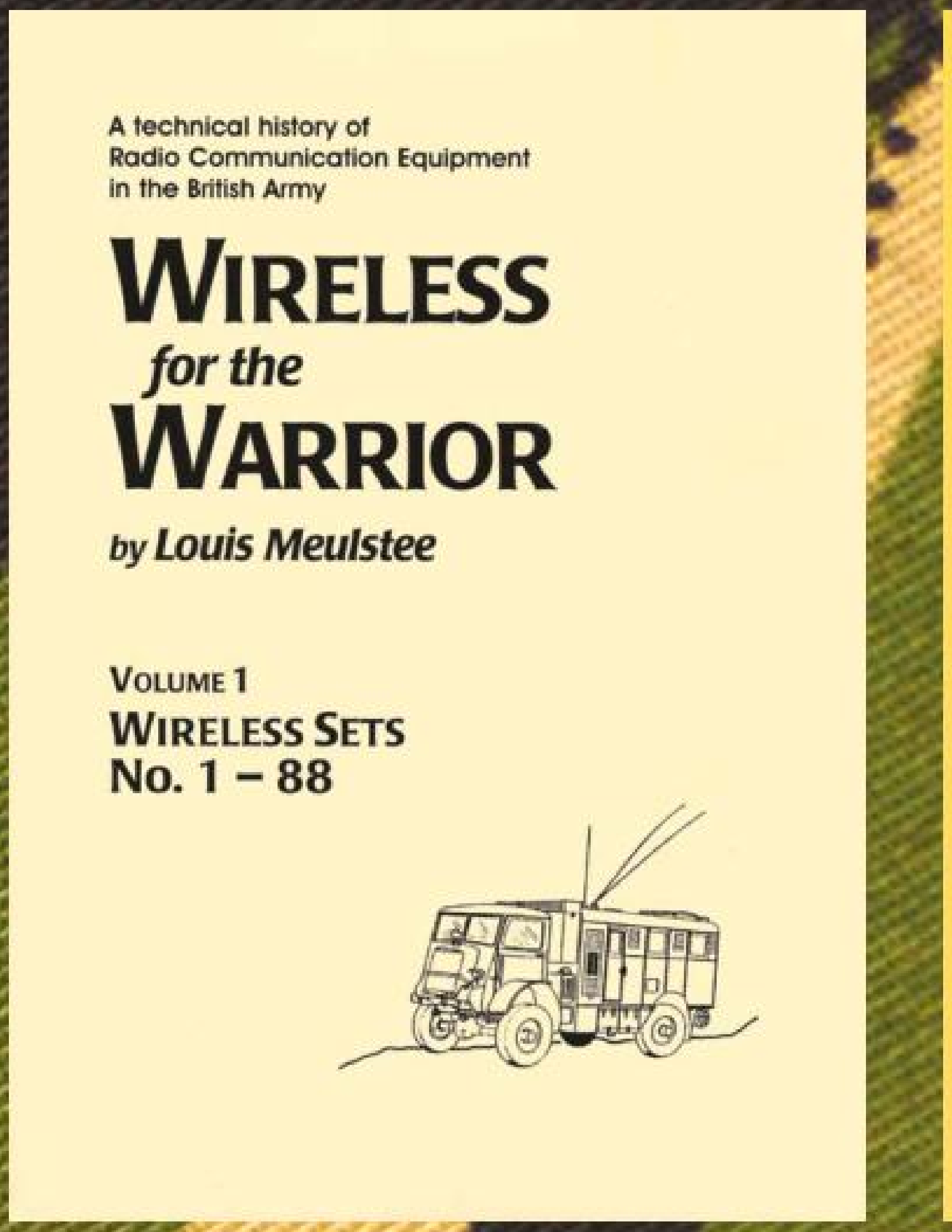
Volume 1 and *Volume 2* cover transmitters and transceivers used between 1932-1948. An era that starts with positive steps taken to formulate and develop a new series of wireless sets that offered great improvements over obsolete World War I pattern equipment. The other end of this timeframe saw the introduction of VHF FM and hermetically sealed equipment.

Volume 3 covers army receivers from 1932 to the late 1960s. The book not only describes receivers specifically designed for the British Army, but also the Royal Navy and RAF. Also covered: special receivers, direction finding receivers, Canadian and Australian Army receivers, commercial receivers adopted by the Army, and Army Welfare broadcast receivers.

Volume 4 covers clandestine, agent or 'spy' radio equipment, sets which were used by special forces, partisans, resistance, 'stay behind' organisations, Australian Coast Watchers and the diplomatic service. Plus, selected associated power sources, RDF and intercept receivers, bugs and radar beacons.



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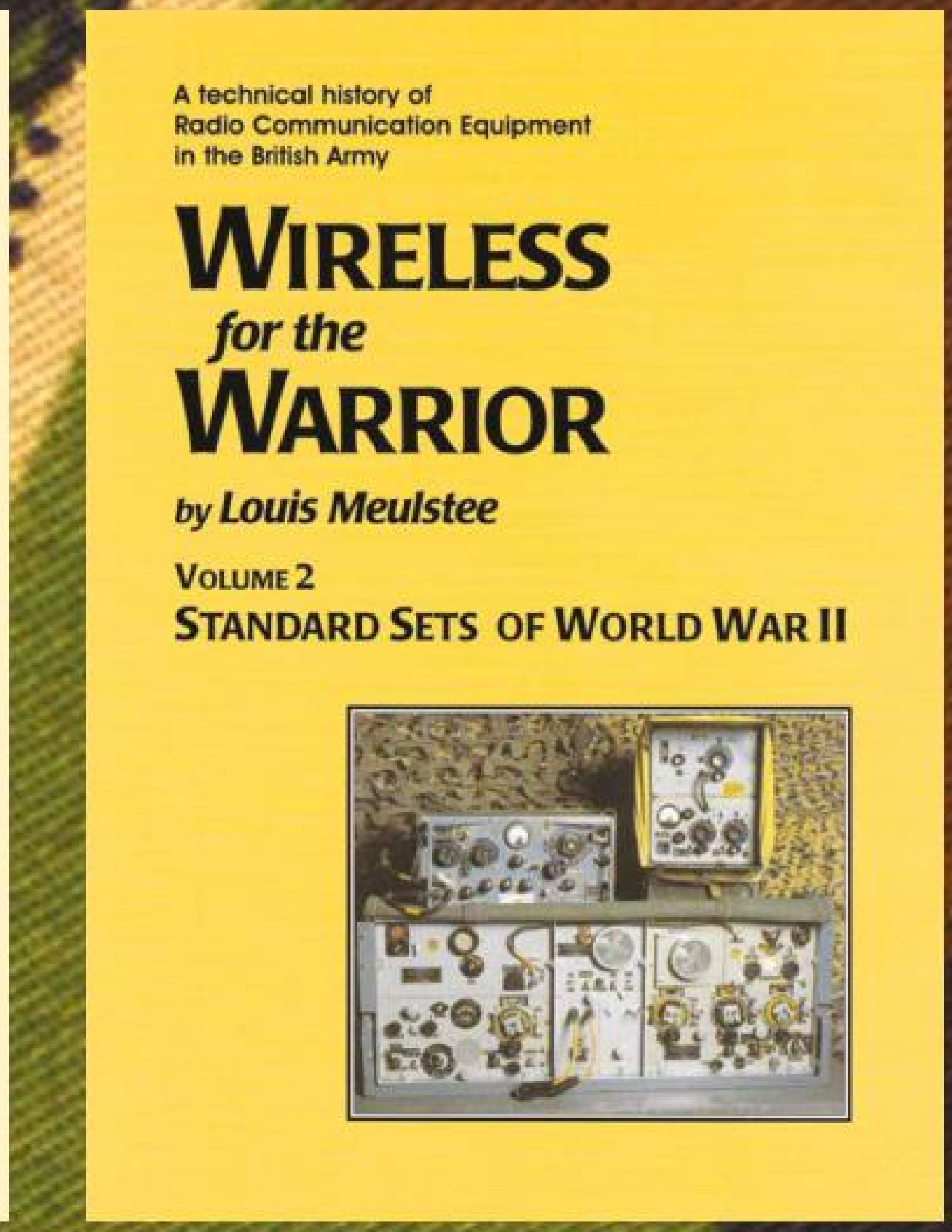

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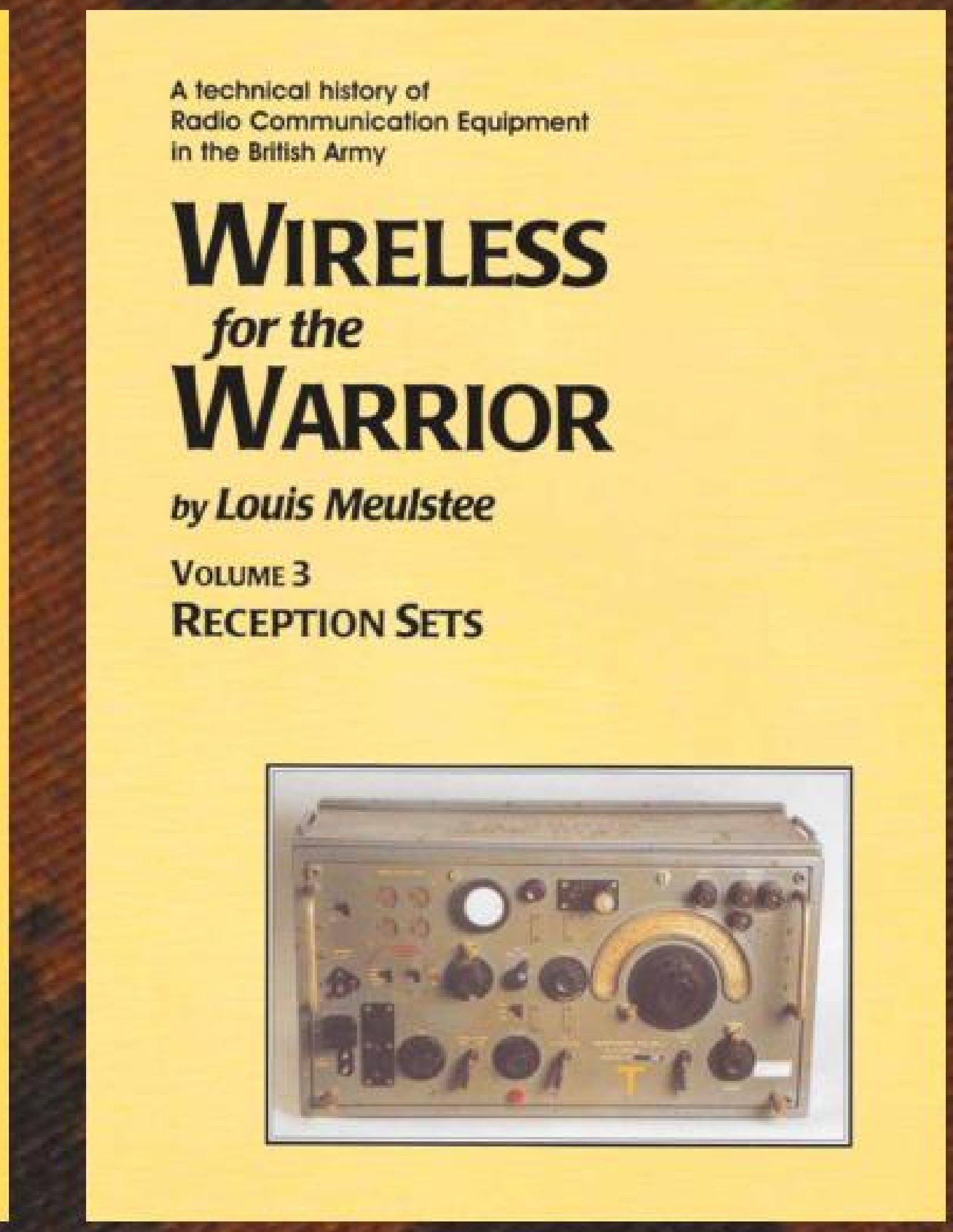

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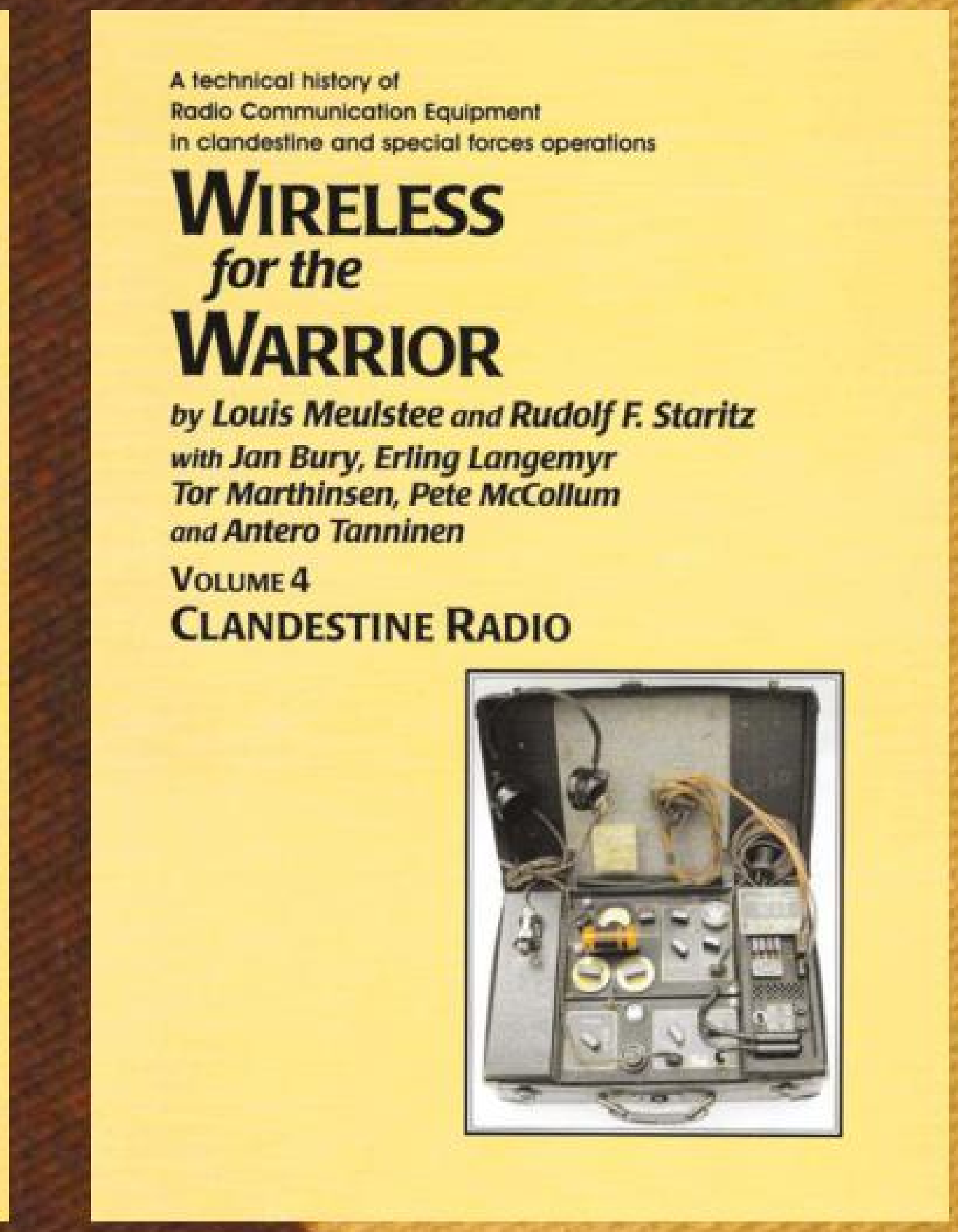

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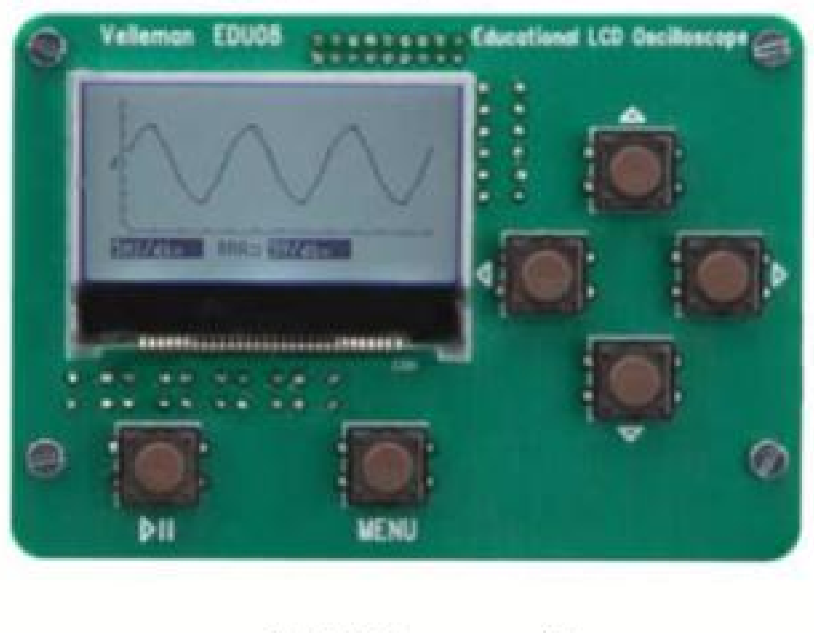

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All reasonable precautions are taken to ensure that the advice and data given to readers is reliable. We cannot, however, guarantee it and we cannot accept legal responsibility for it.

A number of projects and circuits published in *Practical Electronics* employ voltages that can be lethal. You should not build, test, modify or renovate any item of mains-powered equipment unless you fully understand the safety aspects involved and you use an RCD (GFCI) adaptor.

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Important advice

Last month, we published an excellent project, *Driveway Gate Remote Control for sliding and swinging electric Gates* by Dr Hugo Holden. It's a clever design based around common and easily sourced TTL logic ICs. A reader phoned me to say that readers and potential constructors do need to see this as only part of the design. If your automated/motorised gate is accessible to, or ever likely to be operated by anyone other than you, then you must comply with all relevant safety regulations – and yes, such gates are specifically referenced in UK law (and doubtless outside the UK too). The safety systems commercial gates use include, but are not limited to, infrared beam or radar interrupts to ensure that anyone near the gate cannot be trapped, crushed or otherwise harmed. The *PE* design as presented does include provision for limit switches, so it shouldn't be difficult to add additional stop functionality. It's better to be safe rather than sorry, so do please take this advice seriously.

We try to make all *PE* designs as safe as possible. This usually means being careful with amps and volts, especially if sourced from the mains, but all projects need to be viewed as potential hazards. Often, common sense will cover possible dangers – don't let small children near circuits with a button cell, they are a real choke hazard. However, in other areas a little more research may be necessary, so do please always consider this. If you don't know or understand a risk then don't plough ahead regardless – ask someone with knowledge and experience.

Techno Talk – the end of an era …

Last – but definitely not least – in this issue we bid a fond farewell to Mark Nelson, who after 20 or so years is retiring from the *Techno Talk* column in *Practical Electronics*. I will greatly miss his keen eye for the strange, unusual, fascinating and unexpected that regularly crops up in the hugely diverse electronics universe. From nanogenerators embedded in skin-worn patches and activated by body movement to PCBs made from mushrooms, Mark had an uncanny knack for hunting down brilliant stories and condensing them into a quick, coffee-break-sized one-page read. Trust me, writing page after page of comment on fascinating topics is relatively easy. Squeezing several stories into a thousand words is a rare talent. All of us at *PE* wish Mark the very best for the future.

… and the start of a new one

That's the sad news, but the good news is that the *Techno Talk* column lives on! *PE's* very own Mr Cool Bean, Clive 'Max' Maxfield will be taking on the mantle of *Techno Talk* scribe. Max has an insatiable appetite for fascinating (and occasionally ridiculous) technology stories, so the column couldn't be in safer hands – Max, over to you!

Matt Pulzer
Publisher

It's handover time

Techno Talk

Mark Nelson

After 20 years of writing this column, I feel it is time to take a rest and let somebody else take a share of the fun. From next month, this column will be written by the indefatigable cool bean who goes by the name of Max Maxfield.

In last month's article we examined how mushrooms can magically make PCBs and other kinds of substrate for supporting electronic components. But mixing applied electronics and plant life is not just a one-way process. Bioelectronics can also return the favour and promote sustainability in the great outdoors. For example, a young German start-up called Treesense (**https://treesense.net**) which is a spin-off of the Technical University of Munich, is one organisation that's turning the tables.

Making trees talk

All of its products combine the disciplines of arboriculture, electrical engineering and advanced data science. 'By using technology, our aim is to precisely understand the world of plants and contribute to the ecological sustainability of the planet' is its motto.

One example is Treesense Pulse, a sensor the size of a small smartphone that plots the relative change in water content in a tree based on regular impedance measurements in the tree's xylem channels. Understanding changes in a tree's water transport system indicates tree activity, and ultimately, its true health. This 'wearable for a tree' offers potentially vast cost saving – a city can use the Internet of Things to deploy and maintain the sensors, while bespoke data analysis provides predictive maintenance for vital tree irrigation.

Arcs and sparks

Have you ever walked in the dead of night through a place where high-voltage electricity pylons cross your path? If you have, you may well have encountered the cacophony caused by leakage from the power lines, with constant crackling and sizzling that sounds like bacon being fried, only much louder. The effect is normally audible but not visible.

Invisible that is to you and me, but not to all wildlife. A 2014 report by University College London stated that animals may deliberately avoid high-voltage power cables because of flashing ultraviolet light that is undetectable to humans. Although the suspended cables are not a physical barrier, the avoidance may persist for decades after the lines are built. Scientists' findings indicated that power lines give off ultraviolet as irregular flashes at insulators and as a standing corona along the cables. Ultraviolet sensitivity is widespread among mammals, including reindeer; birds are able to see it too.

The subject is particularly problematic in Scandinavian countries, where people are demanding that power lines be located away from wild and semi-domesticated reindeer – the latter are herded by indigenous Sámi people, who depend on the animals. The hapless animals find the flashing UV light terrifying, even at distances of several kilometres, and choose to avoid the power lines. The effect may be more pronounced in snowy areas where the ultraviolet light is reflected and scattered by snow.

The herders, who rely on the animals for their livelihoods, cultural identity and food, are now suffering substantial loss of grazing land for which they have successfully sued power companies.

New nixies

Do you like nixie clocks? For me, they have an irresistible fascination and maybe for you as well. If so, and you feel like indulging your urges, take a look at the XXL-size examples made in Ukraine and offered by Millclock (**https://millclock.com**). That website is fascinating enough, but since a 22-minutes-long video is even more impressive, visit **https://youtu.be/S677EQZ_wns** to get your fill. In another Millclock video – **https://youtu.be/uHv1f4_tDv4** – you can watch the nixie tubes actually being made – amazing stuff! And if that's not enough, just pig out some more at: **https://youtu.be/wxL4ElboiuA**

Repair and reuse?

You may have heard about a proposed 'right to repair' for electrical and electronic products under discussion by the European Commission, with a view to saving expense for consumers and minimising the amount of potentially repairable goods that end up in landfill. This right to repair is seen as a key element of the European Green Deal, the EU's roadmap to reach climate neutrality by 2050. My response is 'what's not to like about this?' and my only regrets about it is that, a) it is unlikely to apply to goods that you have already bought, and b) it may not be adopted in countries like ours that are not members of the EU.

For tinkerers like me and (presumably) you, it's great news as now we should be able to buy spare parts and technical manuals. After all, there is something intensely appealing about repairing things instead of junking them. Now, armed with a service manual and easy access to spare parts, the likelihood of reviving them should be high. All the same, this good news will only intensify the frustration of being unable to repair other consumer durables of greater age that have suddenly given up the ghost.

This thought brings to mind a stimulating blog post article entitled, *The Death Of Schematics*, which echoes the growing difficulty of repairing older electronic devices. It will not take long to read, so I won't spoil your enjoyment by trying to summarise it here. Instead, just go to: **https://bit.ly/pe-mar23-rep**

Who on earth still uses floppy discs?

Since you ask, many important, even critical organisations around the world. Most of them are in the manufacturing or aviation industries, But, there may now be only one firm that still sells and recycles the raw discs. If you wish to discover more, I recommend you visit **https://bit.ly/pe-mar23-disk** – its surprising content is well worth a read!

And finally

I am signing off for the last time and hope you found something of interest. I thank you for your eyeballs and restate my particular thanks to the loyal readers who, over the years, sent in thoughtful comments or submitted ideas and topics for discussion in this column. Please continue to do this for the new scribe, and do carry on enjoying our uniquely satisfying hobby of *practical electronics*.

Exclusive offer

Win a Microchip PIC32CM JH01 Curiosity Pro Development Board

Practical Electronics is offering its readers the chance to win a Microchip PIC32CM JH01 Curiosity Pro Development Board (EV81X90A) – and even if you don't win, receive a 15%-off voucher, plus free shipping for one of these products.

The PIC32CM JH01 Curiosity Pro Evaluation Kit is ideal for evaluating and prototyping with the 5V PIC32CM JH01 ARM Cortex-M0+ based microcontroller (MCU).

The PIC32CM JH MCU is the industry's first MCU based on the Arm Cortex-M0+ architecture with AUTOSAR support, Memory-Built-In Self-Test (MBIST) and secure boot.

The PIC32CM JH is compatible with AUTOSAR, an open-software architecture, providing suppliers with the ability to change to lower-level hardware but keep the original application code, making it easier to migrate between different designs. AUTOSAR-ready is designed to streamline the development process and reduce overall costs. When using AUTOSAR, Microchip offers ASIL B microcontroller abstraction layers (MCALs) for functional safety applications – providing the lower-level hardware interface to the MCU.

Additionally, it features the peripheral touch controller (PTC) with Driven Shield+ as well as analogue, including ADC, DAC and analogue comparators.

The kit has an Arduino Uno connector and extension headers to expand development. It includes an on-board embedded debugger, eliminating the need for external tools to program or debug. The kit also has a security element (TA100) to further extend the security functionality of the MCU.

These devices are supported by the MPLAB development ecosystem, which includes MPLAB X Integrated Development Environment (IDE), the MPLAB XC32 Compiler and our free-to-use MPLAB Harmony embedded software development framework.

The PIC32CM JH01 Curiosity Pro evaluation kit contains the Microchip Embedded Debugger (EDBG) for on-board debugging. The EDBG is a composite USB device of the following three interfaces:

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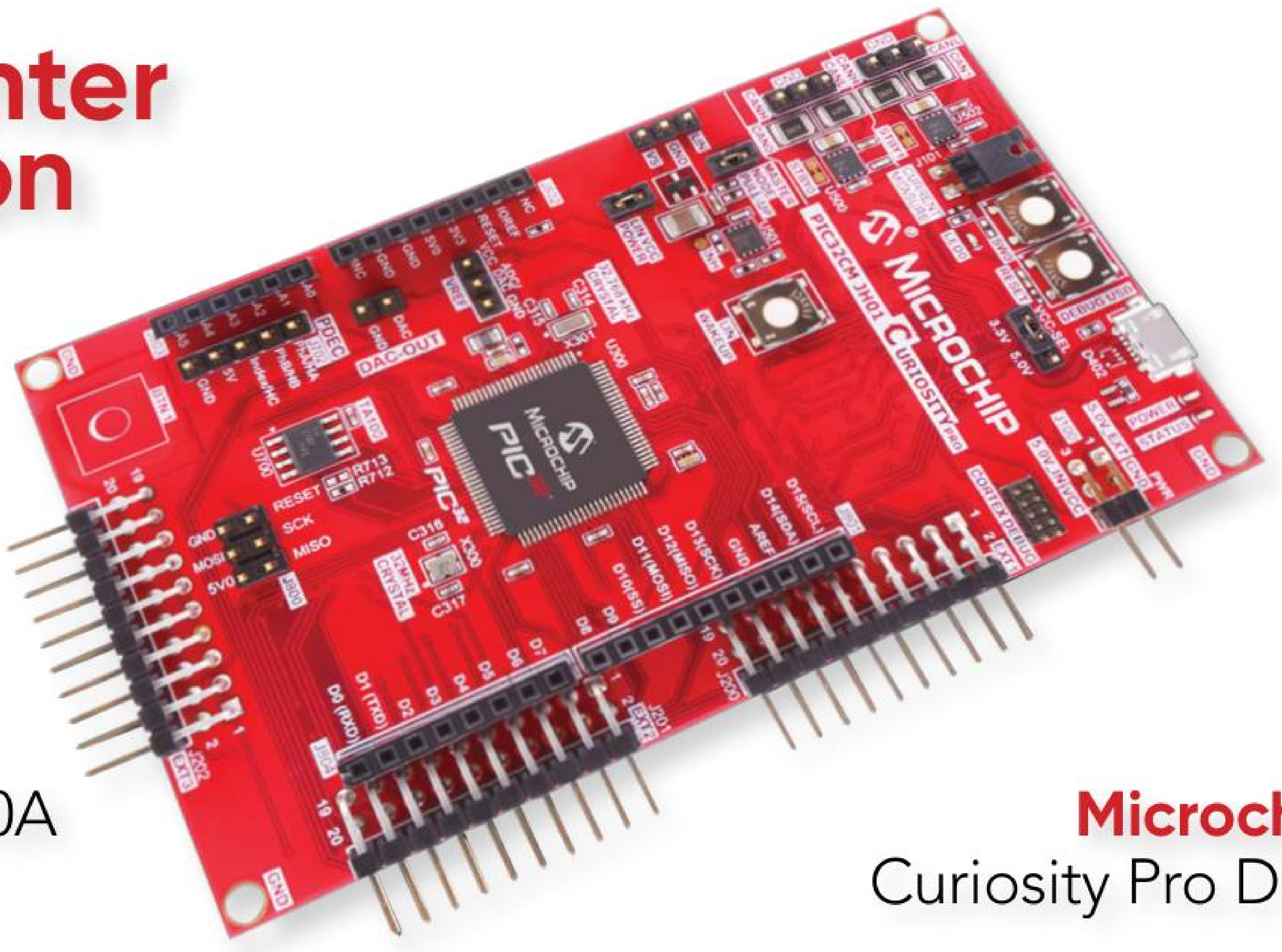


Microchip EV81X90A

Microchip PIC32CM JH01 Curiosity Pro Development Board

How to enter

For your chance to win a PIC32CM JH01 Curiosity Pro Development Board or receive a 15%-off voucher, including free shipping, enter your details in the online entry form at:

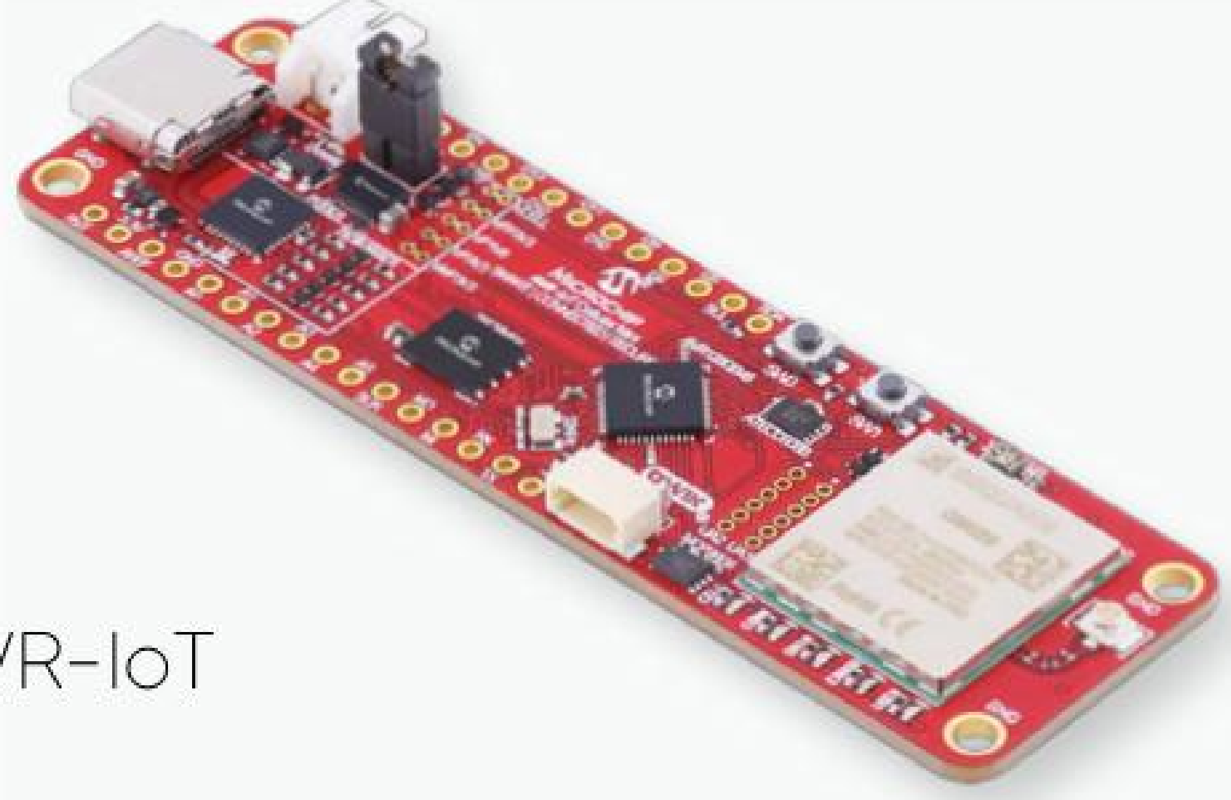
https://page.microchip.com/PE-JH01.html

Closing date

The closing date for this offer is 28 February 2023

November 2022 winner

Max Gibson



He won a Microchip AVR-IoT Cellular Mini

The Fox Report

Barry Fox's technology column

Keeping one step ahead of scammers is a full-time task

Few people now fall for the mail shots, flyers or emails that congratulate us on winning or inheriting a fortune, and which costs money or needs bank details to collect.

More of us are now wise to the way scammers using VOIP can spoof their calling number to match publicly available official numbers – so that the recipient's phone shows the scam caller as 'Bank', 'Building Society' or 'Credit Card'.

One of the cleverer recent tricks is where a random cold caller to your mobile says he (or she) is from your cellphone service provider. While you are taking the call, the scammer uses the service provider's website to send a 'lost password' text message with 'verification code' to your mobile 'to prove it's a genuine call'. If you then read out the code the scammer can take over your account, using stored credit card details to buy credit for another phone, start a new contract and cause much time-consuming grief.

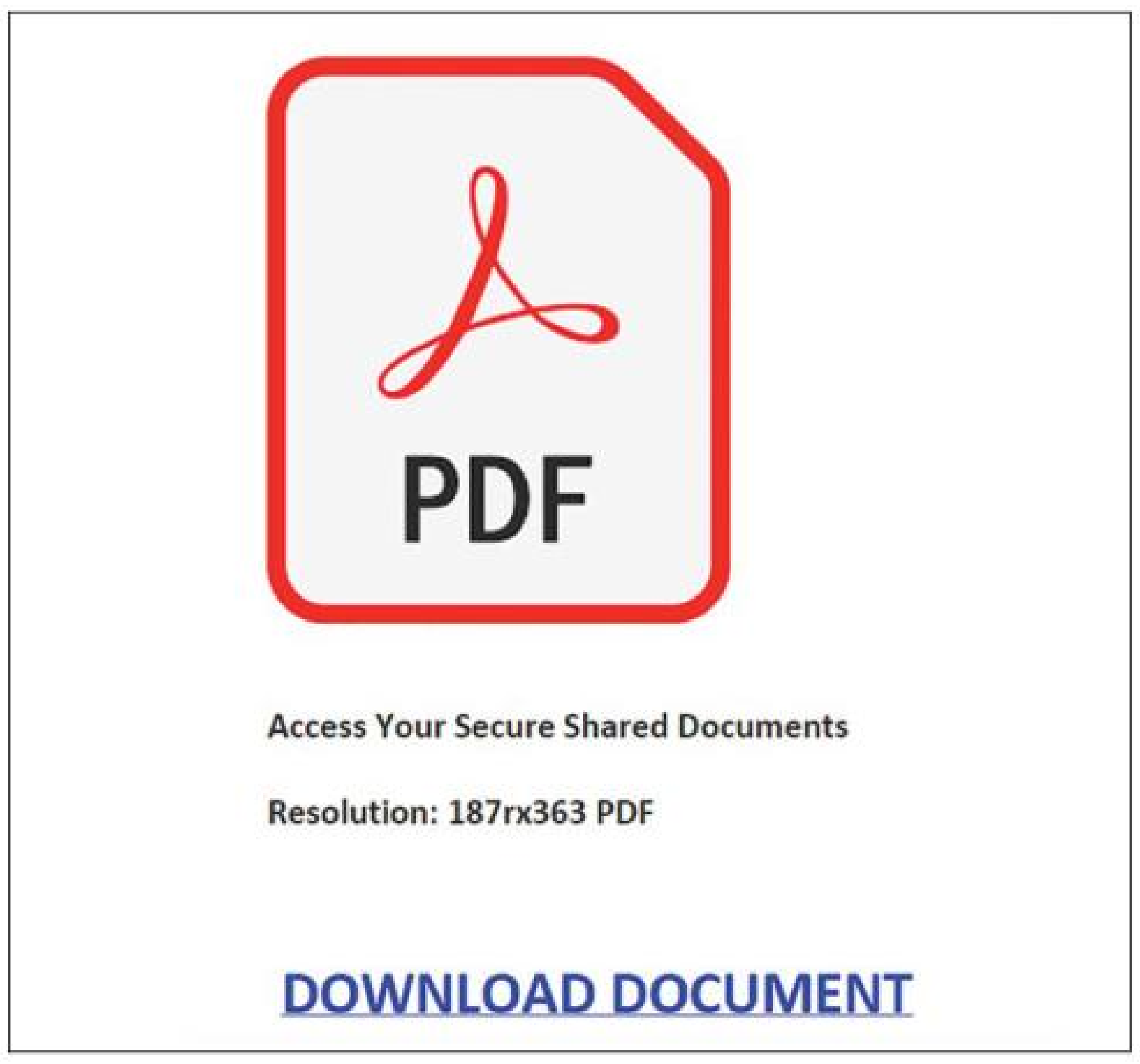
And, however carefully we protect our own online life, we still remain at risk from others who exercise less care – even large companies with professional IT support.

Ally Pally refund

Such was the case recently after I had been in email correspondence with the Alexandra Palace charity in North London. Although the reason for the correspondence is interesting, it's not essential to the scam which followed. Suffice to say that the restored old theatre in the Ally Pally building, under the old studios and transmitter tower which broadcast the UK's first TV services, had staged a *probably excellent* part-musical play about Tom, Dick and Harry, the Great Escape tunnels dug out of Stalag Luft III during World War II.

I say 'probably excellent' because the AP theatre staged the show 'in the round', without radio-miking the actors. So, at any given time, the large audience ringed around the stage were hearing direct sound from roughly just a quarter of the cast, with the rest of the sound bouncing unintelligibly off the hard walls, floor and ceiling dome.

The AP management thanked me for my detailed acoustic-electronic suggestions, agreed that I was right to say the production should have been radio-miked and said they would be installing the necessary equipment later in the show's run (but presumably, until then audiences would continue to strain their ears). I reckoned I was entitled to a refund for paying for a largely inaudible event, but management minions just sent me standard-form email refusals. So, since as much as anything, I don't like being fobbed off with semi-automated responses to considered arguments, I pursued – and eventually – got my refund.



Access Your Secure Shared Documents

Resolution: 187rx363 PDF

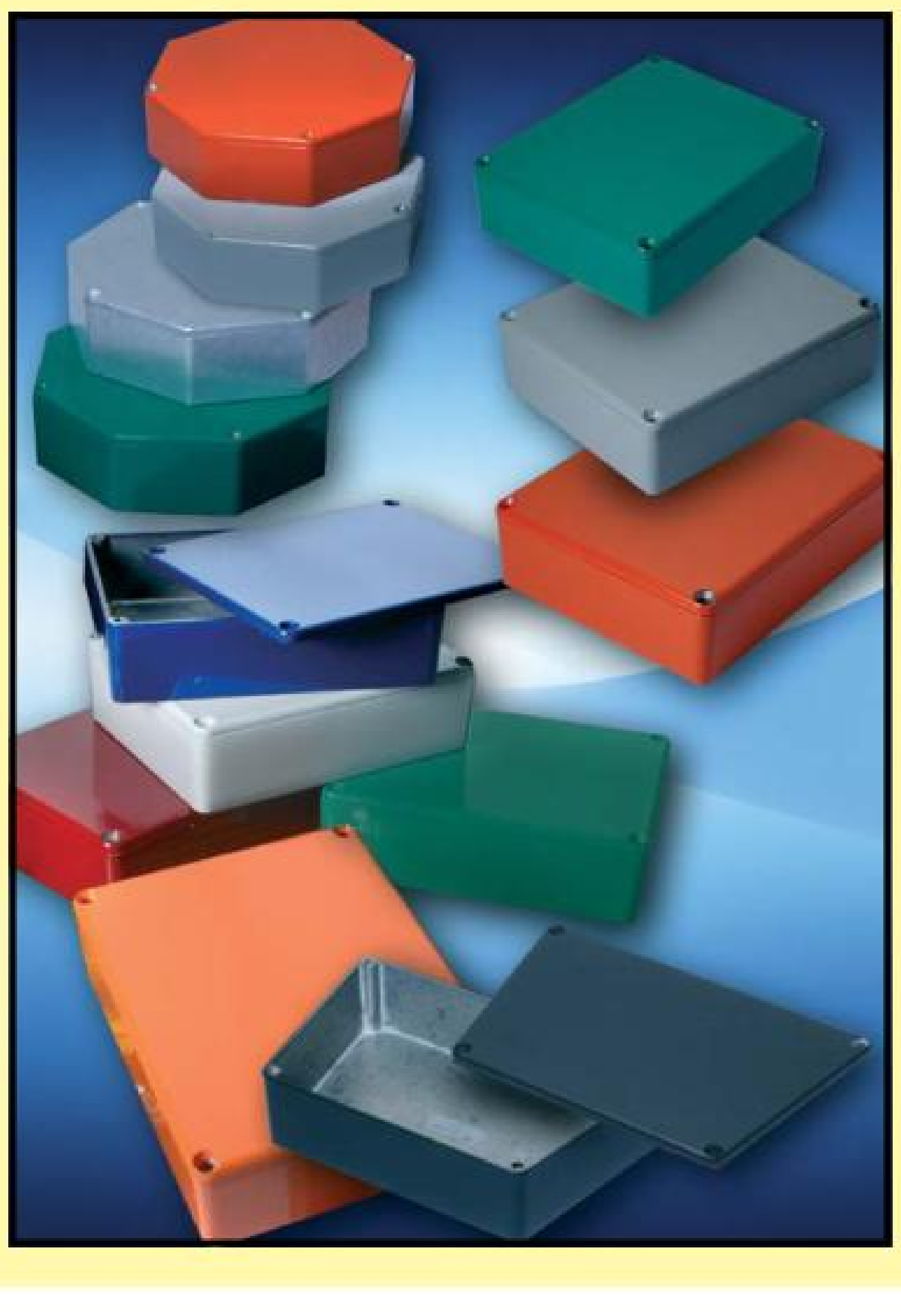
DOWNLOAD DOCUMENT

STOP! Always ask yourself by whom and why you are being asked to click on a link.

All was forgotten until, a few months later, I received an email from the Alexandra Palace Finance Department which – as often now happens with business or medical communications – came with a password-protected attachment. As I had no account and no password, I queried the request and got back an assurance that the attachment was safe to read. But I still had no Ally Pally account or password. So, I never read whatever I'd been sent.

Have I been scammed?

Fast forward a few months and I learned that the correspondence had been a scam.



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I quote AP's Director of Finance and Resources: 'My email account was hacked and the email you received from me was malicious and from a hacker. The response you received to your query was from the hacker… I sent out a huge number of responses reassuring people that these were indeed malicious and should be deleted.'

But, *I* got no such legitimate email. Should I be worried about malware or ransomware?

The Director re-assured: 'We have been advised by our third-party IT team that this was a relatively unsophisticated attack. They got access to my mailbox by me potentially using an unsecure public Wi-Fi… there has been no malware or ransomware detected…we have been advised that any recipient should delete the email and if not already done, passwords changed *to prevent any subsequent malicious access attempts*.' (my italics)

Passwords

A BBC TV 'expert' recently gave similar general blanket change-password advice in response to a viewer's unrelated question.

Setting up new email passwords is not a trivial matter; it means that all user's devices must be changed to the new password (phone, laptop, desktop, tablet). In the case of Google GMail the address is tied to a wide range of services which must all be reset to the new password.

But what does changing passwords achieve if a hacker has simply stolen email addresses from a third party's address list? The hacker has stolen the email address, not the password, because email passwords do not travel with email addresses.

A colleague of mine surmises that, 'it's not at all unlikely that your email password is already out there in some 'dark web' database containing millions of such addresses. As such, it's of little value to anybody and may well just be being ignored. However, if a bad actor has obtained your email address together with a set of emails containing some interesting financial information, your email password may well have leapt in value and be worth purchasing on the dark web.'

Says Alexandra Palace, presumably on advice from its IT advisers: 'We have been advised that the approach this attack has taken means that if you have clicked on the link contained within the email and entered your own email address and password (as advised by the hacker) they will have captured both bits of information.'

Most IT-savvy folk will not enter their email address and password if asked to log into a third-party secure online locker. They will recognise that there is no connection between email security and locker security. But someone less familiar with online risks and perhaps in a hurry or worried or both, may well give it a try. In this case, the hacker cleverly created 'urgency' by saying the link would expire in two days; and when recipients replied to the scam mail querying sign-in, the scammer replied with reassurance that the email and site were safe.

Later, of course, the scam site was blocked with dire public warnings. But blocking can only happen after early accessors have fallen foul; and the scammers have gone on to create fresh traps elsewhere.

In my case I gave no information away so felt confident in not changing my email passwords. But I did make the mistake of replying to the original email, thereby unwittingly confirming that my stolen email is 'live' and thus worth more for sale.

Use VPN

If you are out and about with a laptop, then linking to a third-party Wi-Fi source without VPN (Virtual Private Network) protection is a really risky. I would hope that an IT specialist company employed by a large organisation would put staff VPN protection in place, or at least forcefully advise staff to use only public Wi-Fi access points with well-known service names, like those ftom O2, Virgin or a national rail line. It's too easy for a scammer to create a phoney Wi-Fi access point and suck sensitive data out of victims' mobiles.

Says Ally Pally: 'We think we have now bottomed out the cyber breach and apologise once again for your data being exposed in this way. We have taken steps to raise awareness of this type of attack internally and put in place changes to our IT infrastructure to mitigate this happening again.'

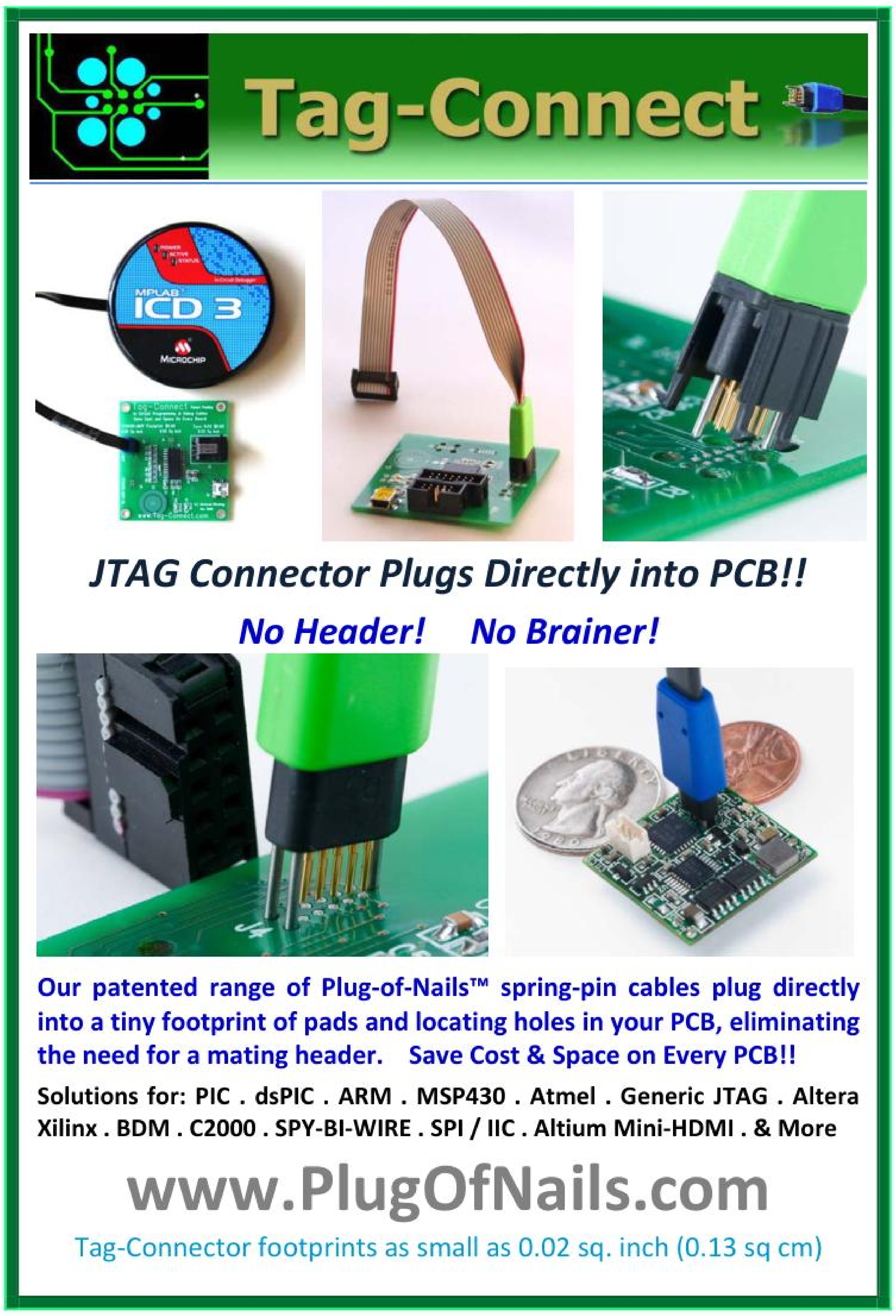
But there will still be countless other employees of countless companies that haven't even thought about the risks they are running with customers' data by using unsecured laptops on any available Wi-Fi they find in a coffee shop.

Public education on the risks of using public Wi-Fi and practical advice on VPN is pitifully poor. Even the companies selling security solutions aren't doing it.

A self-promoting cybersecurity security company that specialises in VPN recently sent out a press release listing the best ways to avoid the theft of 'account login credentials, personal information, or bank and credit card information'.

I asked why there was no warning on public Wi-Fi and no mention of VPN. I, for one, would have welcomed some expert advice to try, use and pass on.

The reply I received hardly inspired confidence. Simply: 'This is a great tip … so feel free to include.'



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Net Work

Alan Winstanley

Our Internet and technology column is optimistic about small satellite launching programmes in the UK, despite recent setbacks; and we also rediscover the real, historical roots of documentation and the Information Age.

This month's Net Work column was going to lead with the latest space news from Britain, hopefully buoyed by Virgin Orbit's successful launch of a crop of small satellites from Spaceport Cornwall in south-west England (see last month). As I was writing, one eye was on my dual monitors, my PC TV card showing events unfolding at the night-time launch event in Cornwall in January. With the backing soundtrack of the Rolling Stones' 'Start Me Up', I grabbed screenshots of the *Cosmic Girl* 747 taking off before thousands of cheering spectators, with infographics showing the fast-diminishing fuel level of the LauncherOne rocket as it headed into orbit.

With *Cosmic Girl* returning to land, everything looked rosy, so I pressed on with my routine, until a news alert on my phone half an hour later said that the rocket had failed to reach orbit. The last I heard before I switched off in the early hours was that the rocket had suffered an 'anomaly'. It would turn out to be a failure of the rocket's second-stage engine. After reaching hypersonic speed the rocket reached space but failed to achieve its intended orbit. Next morning, we learned that LauncherOne had fallen into the Atlantic somewhere, one good reason why the flight path was over open sea.

In late 2022, Skyrora attempted to launch a Skylark L from Iceland ahead of a planned full orbital launch from the UK in 2023. It fell into the sea.

Obviously, this was a major setback, but bystanders interviewed in a TV vox-pop still seemed quite upbeat and stoical. The English county of Cornwall got some welcome publicity and the new spaceport had been built on a small airstrip *without* the largesse of a NASA-sized budget; besides, four previous Virgin Orbit missions in the US had successfully placed a total of 33 small satellites into orbit for the US military and government, flying on trajectories that were impossible for conventional (vertical) launches to follow. Richard Branson has refocused his space ambitions away from the indulgent *Virgin Galactic* space tourist plane (*Net Work*, July 2021) and towards small satellite launches instead, so hopefully the next mission will be a successful one and will restore credibility in the Virgin Orbit launch programme.

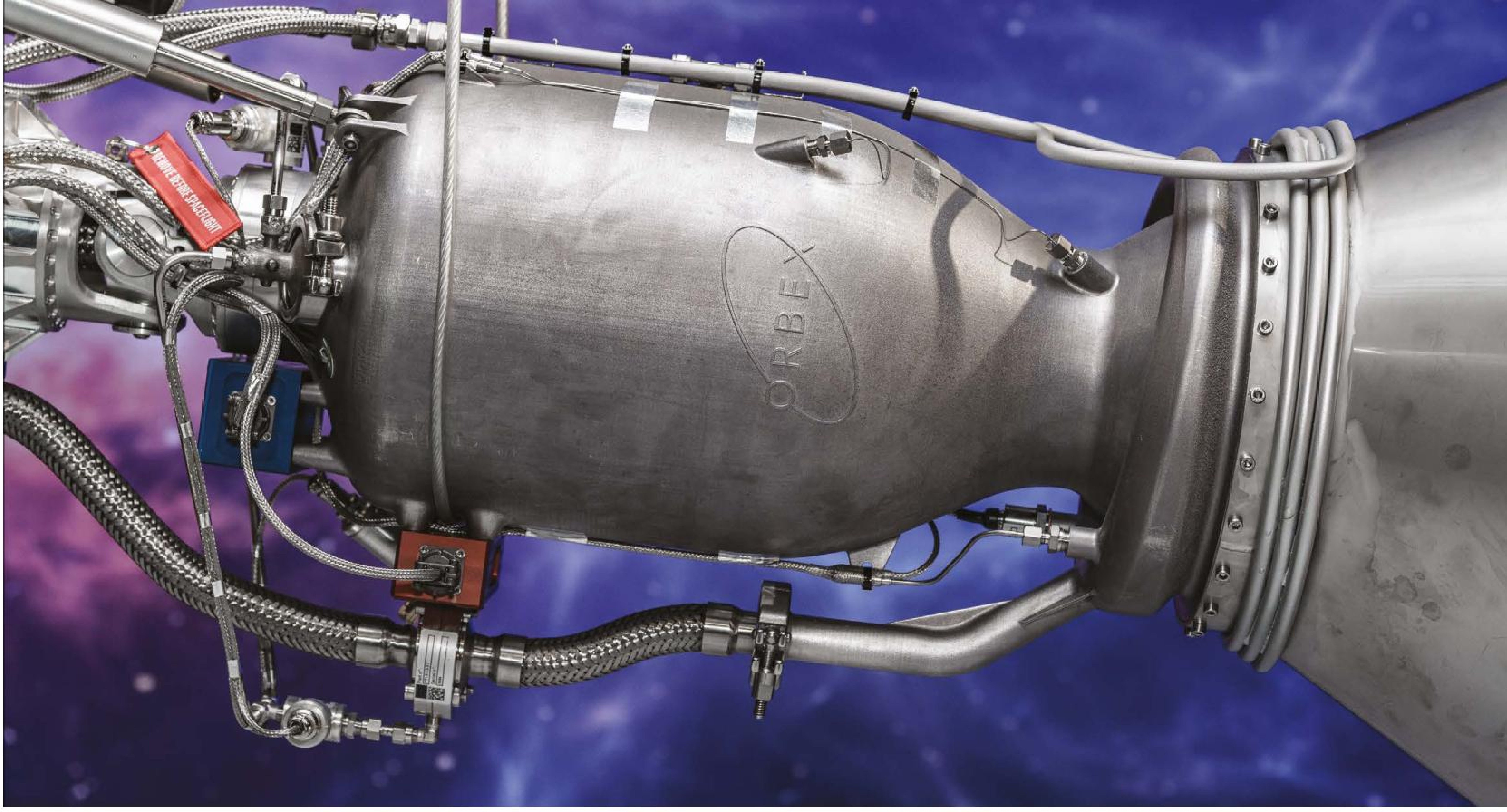
SPACEPORT CORNWALL
Virgin
Virgin ORBIT
FLIGHT TEST

Better luck next time: Virgin Orbit's first launch from UK soil was unsuccessful after the rocket's second-stage motor failed.

Can't get no satisfaction

There is more competition gunning for the UK's emerging small satellite launching business, starting with Skyrora, a firm which 'attempted to launch' its home-grown Skylark rocket from a site in Iceland late last year. Sadly, the rocket nosedived into the Norwegian Sea instead, but Skyrora gained useful experience in logistics and hands-on practice using its mobile launch complex, working closely with the Icelandic government. The mission is just one more bump in the learning curve, as Lee Rosen, Chief Operations Officer at Skyrora, said: 'I can assure you that despite the best design, build, and test preparations, anomalies still unfortunately do happen.' Virgin Orbit will doubtless agree. Skyrora is planning to produce an intriguing range of small launch vehicles and space tugs, with more news available on **skyrora.com**

There are plenty of other new developments to look forward to, including an entirely separate operation taking shape at Space Hub Sutherland, located on the northernmost tip of Scotland. The new facility – dubbed 'Scotland's



The Orbex engine will use 3D parts printed on Europe's largest custom-made AM metal-printing machine.

Sustainable Spaceport' – will be the world's only carbon-neutral launch site and is being leased in its entirety for 50 years by Orbex, a UK-based small satellite start-up with design and production facilities based in Denmark. The company is currently developing a high-technology vertical microlauncher rocket fuelled by a bio-propane propellant, which will have 96% lower carbon emissions compared with rival fossil-fuelled systems, Orbex says.

The Orbex Prime launcher, first revealed last May, will have unique 3D-printed engines after the firm commissioned a custom machine from Germany's AMCM GmbH that will be Europe's largest AM (additive manufacturing) metal-printing machine. The process can 'print' components from titanium and aluminium, and this one-piece 3D solution overcomes problems and weaknesses introduced by joints or seams in complex metal components and housings. The bespoke facility will enable Orbex to build more than 35 large-scale rocket engines (seven engines per rocket) and main stage turbopumps every year, the makers say.

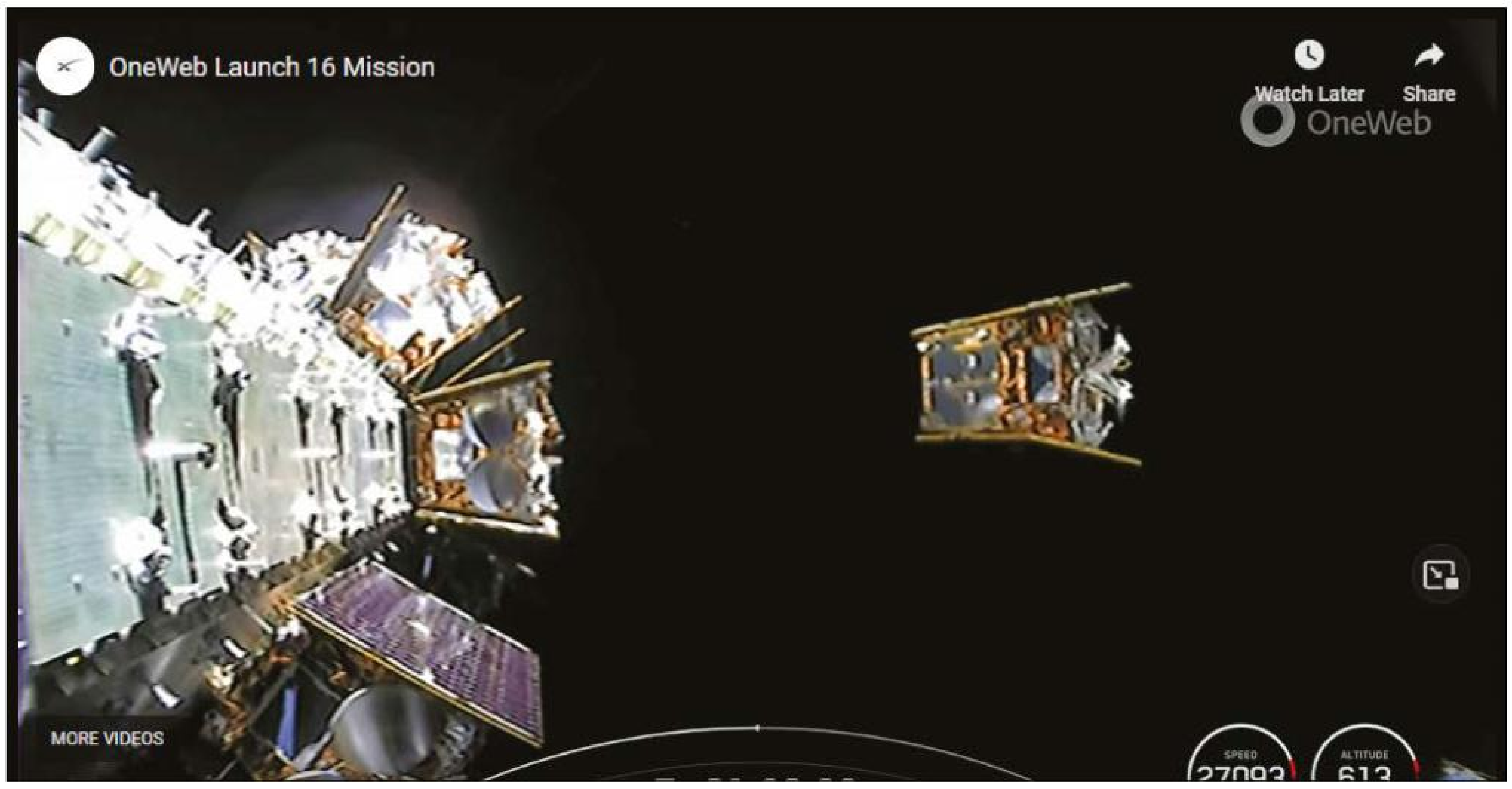
The emerging service has already been awarded 'Preferred microlauncher' status by the European Space Agency, and test launches were scheduled to start from the early 2020s, with launch frequencies of 12 per year. Orbex is supported by the Highland and Islands Enterprise (HIE) agency who write more about the project at: **https://bit.ly/pe-mar23-hie** – readers can track developments at: **https://orbex.space**

In the meantime, Elon Musk's SpaceX launched another 51 Starlink satellites into LEO (low-earth orbit) in mid-January, making some 3,300 in all. The Starlink network is also playing a key role in providing Internet access in the Ukraine war, with some ten thousand Starlink antennae having been delivered to the conflict zone. At the same time, SpaceX graciously launched a second tranche of 40 satellites for its friendly Starlink rival OneWeb, the UK-based satellite communications company that became ensnared in the Ukraine conflict after Russia seized 36 OneWeb launch-ready satellites, valued at $230m, from the Baikonur Cosmodrome in Kazakhstan. This latest mission brings the number of missions flown by SpaceX to an incredible total of 201 launches, and OneWeb now has 542 satellites in LEO to increase its own coverage across the globe.

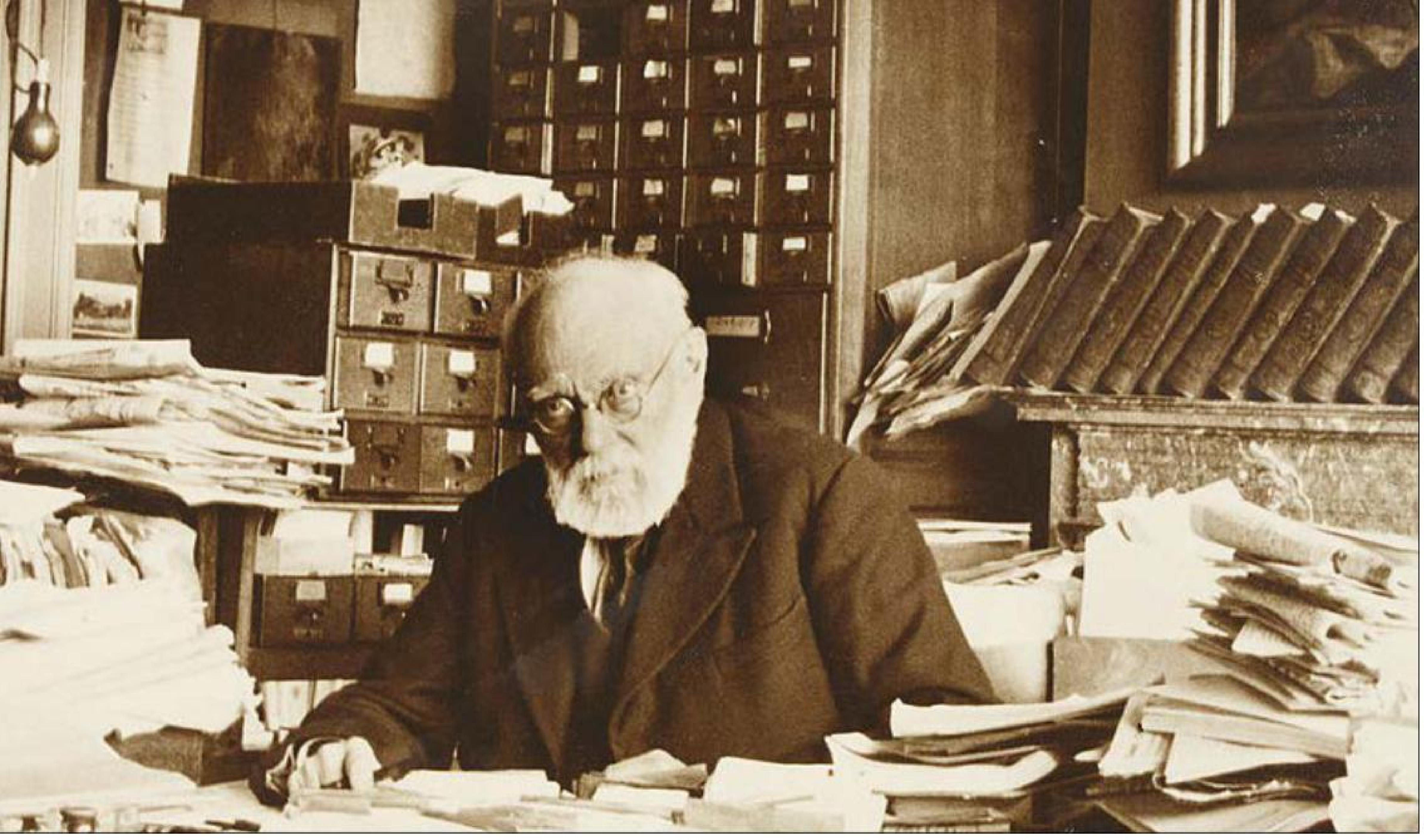
An essential utility

Today's Internet is seen as an essential utility, and at least two generations of users have never known life without the web. The smart home relies on network and cloud connectivity, and controlling a 'smart' bulb or mains socket – for example, via TP-Link's Tapo range described in recent columns – is second nature for a generation that has grown up in a connected world.

Plenty has been written about the Internet's evolution since the late 1980s when scientists working at the CERN particle physics laboratory, located on the French-Swiss border, wanted to access and share technical information and data, but were handicapped by the disparate network of computers on which information was hosted. This led the British CERN scientist Tim Berners-Lee to create a protocol that would allow complex information to be shared more readily over a network. The principles of hypertext markup language were fleshed out, with HTML (HyperText Markup



SpaceX gave Starlink rival OneWeb a helping hand with the launch of 40 more satellites into low-earth orbit in January.



Paul Otlet (1868-1944) co-founded with Henri La Fontaine the International Institute of Bibliography, which later became known as the Mundaneum – for more details, visit: **https://bit.ly/pe-mar23-otlet** (Image: mundaneum.org).

Language) offering the ability to encode or 'mark up' and tabulate textual information, style the text, embed images and include those all-important hyperlinks that allowed users to jump seamlessly from one web page or server to another. Gradually, a language evolved, intended to make data accessible in a consistent way, and Sir Tim Berners-Lee was duly credited (and then knighted) as the 'father of the web'. Web design software such as Softquad's Hot Metal Pro then put web design within reach of everyday home computer users for the first time, as enthusiasts grappled with the use of HTML and FTP (File Transfer Protocol).

There is a project to restore the world's first web address – **info.cern.ch** – at: **https://bit.ly/pe-mar23-cern1** and the first-ever web pages can still be seen at: **https://bit.ly/pe-mar23-cern2**

The topic of Internet etiquette or 'netiquette', a subject that has vanished from today's online vocabulary, was also thought about, and early guidelines were signed off by Berners-Lee himself, see: **https://bit.ly/pe-mar23-cern3**

Building a web presence soon became a must-have for industry, commerce and education, sectors that recognised the need to put their information online and generally interact better with web visitors. One example is Intel's earliest spidered web page from 1996, archived at: **https://bit.ly/pe-mar23-int1**

Graphic content

At a time when web pages contained little more than 'silos' of static information and 'raster' (pixel-based) images (ie, jpegs and gifs), website visitors were surprised to suddenly see actual moving graphics for the first time. In the mid 1990s, the author noted how one web surfer had marvelled at seeing a 'spark' glyph travelling around an Intel web page: it was an early example of an animated .gif. An Intel page from 1999 has another animated .gif and can be found at: **https://bit.ly/pe-mar23-int2**

Early on, the Internet's low-capacity bandwidth meant that static web pages were fit only for carrying text, raster images or lightweight cartoon-style 'Flash' animations. Instead of using blocky pixelated graphics, Flash was a *scalable* vector graphic technology that started life as FutureSplash Animator, a software suite that was acquired by the sadly missed Macromedia, before being swallowed up by the Adobe empire. Adobe Flash was powerful but ultimately insecure, and is now long obsolete (as detailed at: **https://bit.ly/pe-mar23-flash**). However, as current generation web users grew up seeing Flash animations on-screen, the solid-colour cartoon fashion is still with us today, especially on TV commercials.

Today's web pages bear no resemblance to their 1990s origins, with sophisticated styling and layout rules being coded into separate 'cascading style sheet' (CSS) files that need quite a lot of skill to understand and work with. Ironically, this has made core web design far less accessible to non-experts than before. So, instead, pre-built website templates from the likes of Wix, Ionis (formerly 1&1), GoDaddy or Web.com are used to produce sophisticated-looking results with just a few mouse-clicks. More advanced Wordpress users have a choice of flexible drag-and-drop software such as SeedProd, which is enjoyed by a million users.

The Internet userbase of the nineties, hitherto the province of professionals, managerial types, academics, scientists and computer hobbyists, would witness a 'big bang' when everyone climbed onboard thanks largely to aggressive marketing by America Online (AOL). It was said at the time that 'the Internet was cool until everyone discovered it', and the way the web changed for ever is itself a fascinating study, which I hope to cover in a future column.

Paul Otlet: the father of documentation

Although Berners-Lee is associated with the advent of the world-wide web, an interesting publication landed on my desk that sheds light on developments that pre-dated the efforts of CERN to make information accessible to all. According to the book *Cataloging the World* by Alex Wright, an ardent Belgian bibliographer named Paul Otlet (1868-1944) could be considered as the forefather of documentation and the Information Age itself. Just as Stanford computer science students Larry Page and Sergey Brin developed a keen interest in data mining, which evolved into the Google search engine, Paul Otlet had an unquenchable passion for indexing *written* information. He made it his mission in life to catalogue every book, magazine and newspaper – and make them universally accessible, an ambition that was a very tall order in the late 1800s.

The book explains how, in the first half of the 20th century, Otlet foresaw a system of networked computers – or 'electric telescopes' – that would allow people to search through millions of interlinked documents, images, audio and video files. His indexing system would 'unite individuals and institutions of all stripes – from local bookstores and classrooms to universities and governments. He named it a *réseau mondial* or a 'worldwide network'. Otlet prophesied that, 'From a distance, everyone will be able to read text, enlarged and limited to the desired subject, projected on an individual screen. In this way, everyone from his armchair will be able to contemplate creation in its entirety or in certain of its parts.' The name given to this early 20th Century 'web' was the *Mundaneum*.

Otlet toiled tirelessly for half a century to diligently gather and archive all manner of documentation sourced from around the world. The Mundaneum buildings, then scattered around Brussels, would house some 16 million 'data' files, glass plate photographs, postcards and more. Sadly, World War II got in the way, and Paul Otlet's utopian dream of cataloguing a vast wealth of documentation would never be realised. This was also due in no small part to the severe physical and technological limitations of trying to index massive amounts of written information. Today, the Mundaneum – **www.mundaneum.org** – is an exhibition and archive centre located in Mons, Belgium, and travel and visitor information will be found at: **https://tinyurl.com/3pp6dy4b**

Among other things, this fascinating book describes the creation by Otlet and Belgian politician, pacifist and lawyer Henri La Fontaine of a practical methodology for indexing documents, called the Universal Decimal Classification (UDC). This library cataloguing system is still in wide use today, see: **https://udcc.org**

Alex Wright's book also details the evolution of cataloguing and indexing systems in general, highlighting practical filing systems (wooden cabinets and all), and he tells us how one particular centuries-old artefact would transform the process of indexing: playing cards, which were made of a stiff board and to a standard size, and so were ideal for slotting into early library index systems.

Cataloguing the World by Alex Wright (2014, Oxford University Press, ISBN 978-0-19-993141-5), is available at Amazon, for more information see: **www.catalogingtheworld.com.**

Just touching base

When I'm having a busy day at my desk, handling a stream of email, or surfing around on the web, it's at peak periods like these that it's all too easy to click a link or reply to an email by dashing off a few lines, without thinking about it first. Most of us can screen out and delete scams, phishing emails, potentially dangerous file attachments or dodgy-looking web links, but more subtle and sophisticated techniques can also be used to defraud victims without a second thought. Sometimes the damage is already done before the victim realises a few *oh no* seconds later that they have been 'had'.

In one example, a friend's Hotmail account was hacked, and the imposter copied Sarah's writing style exactly, writing that she 'had lost her purse and was in tears', which initially had me fooled. Only when I called her office was it confirmed that the email was an imposter ('Sarah in tears? You must be kidding!'), but it was the closest I ever came to falling for a scam, and I learned a valuable lesson. Others have not been so lucky.

It's very easy to fall for this kind of imposter. A tiny change to an email address, for example, changing an '**l**' (L) for a '**1**' (one) or a '**g**' for a '**9**' would be enough to fool many recipients, sometimes snaring them with elaborate frauds that could cost the victim a small fortune, especially when, for example, property or house sales were involved. An email imposter might manage to convince a house buyer that a solicitor's bank account details were wrong and funds should go to a new account (his). In business or commerce, junior staff might receive fraudulent instructions to change a vendor's bank details and rush out an urgent payment to them, which will deposit cash into a fraudster's account, never to be seen again.

Banks are very keen to highlight the risks of such fraud and will always warn customers not to rush when making payments, but stop, think and check details very carefully first. The best source of advice is the UK finance sector's Take Five website at: **https://bit.ly/pe-mar23-t5** and a comprehensive list of all types of fraud can be found on the UK's Action Fraud website at: **https://bit.ly/pe-mar23-a2z**

Other news

Last December's holiday season saw owners of electric vehicles discovering the limitations of the UK's nascent EV charging network as they travelled around our overcrowded roads. In the worst cases, queues of over three hours were seen in some EV pinch points as owners of Teslas and other marques were forced to wait patiently in line, something I know we Brits are fond of doing, while EV cars jostled for a recharge in the cold, wintry weather – see the video at: **https://youtu.be/3pbrdFnqSBI**

Depending who you ask, between 10-20% of battery electric vehicle (BEV) adopters are reportedly giving up on EV ownership altogether and reverting to petrol (gas) to enjoy greater freedom and less inconvenience. Otherwise, it seems that most EV owners are converts to electric propulsion for life. Post-pandemic sales of electric vehicles continue to rise again in the UK. The Society of Motor Manufacturers and Traders (SMMT) states that in 2022, out of 1.6 million car sales, some 42% of new cars sold were petrol and about 17% were BEVs, making them the second most popular powertrain sold. New diesel car sales trailed at just 5%. Tesla took 3.4% of the UK market, more than twice that of Honda, for example. The UK is once again Europe's second biggest market for new cars, though global component shortages continue to stymie production.

The cute-looking Ora Cat EV from China's Great Wall Motor (GWM) that I introduced in January 2022's column is finally heading onto our roads, but (surprise) the price has leapt from an anticipated £25,000 to £32,000 ($39,000), another reason why EVs are beyond the reach of many motorists in today's market. You can reserve your very own Ora First Edition Cat at: **https://gwmora.co.uk**

Startup EV battery maker BritishVolt (*Net Work*, May 22) has gone into administration after struggling to finish its gigafactory following financial difficulties last year. Work on its super-site in northern England ground to a halt while the firm scrambled to secure more funding, blaming spiralling energy costs, inflation and factory design changes. A cash bailout saw the firm's value plunge by more than 95% as BritishVolt sought new investors to find a way forward. Final delivery of the new plant was due in 2027, according to a report in *Construction News*, but who knows what will happen now with the company's half-finished assets.

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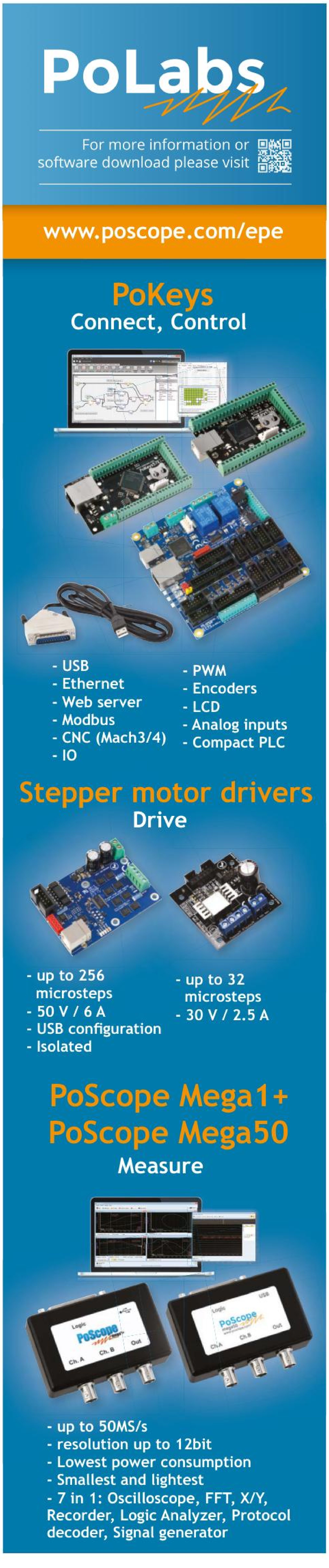

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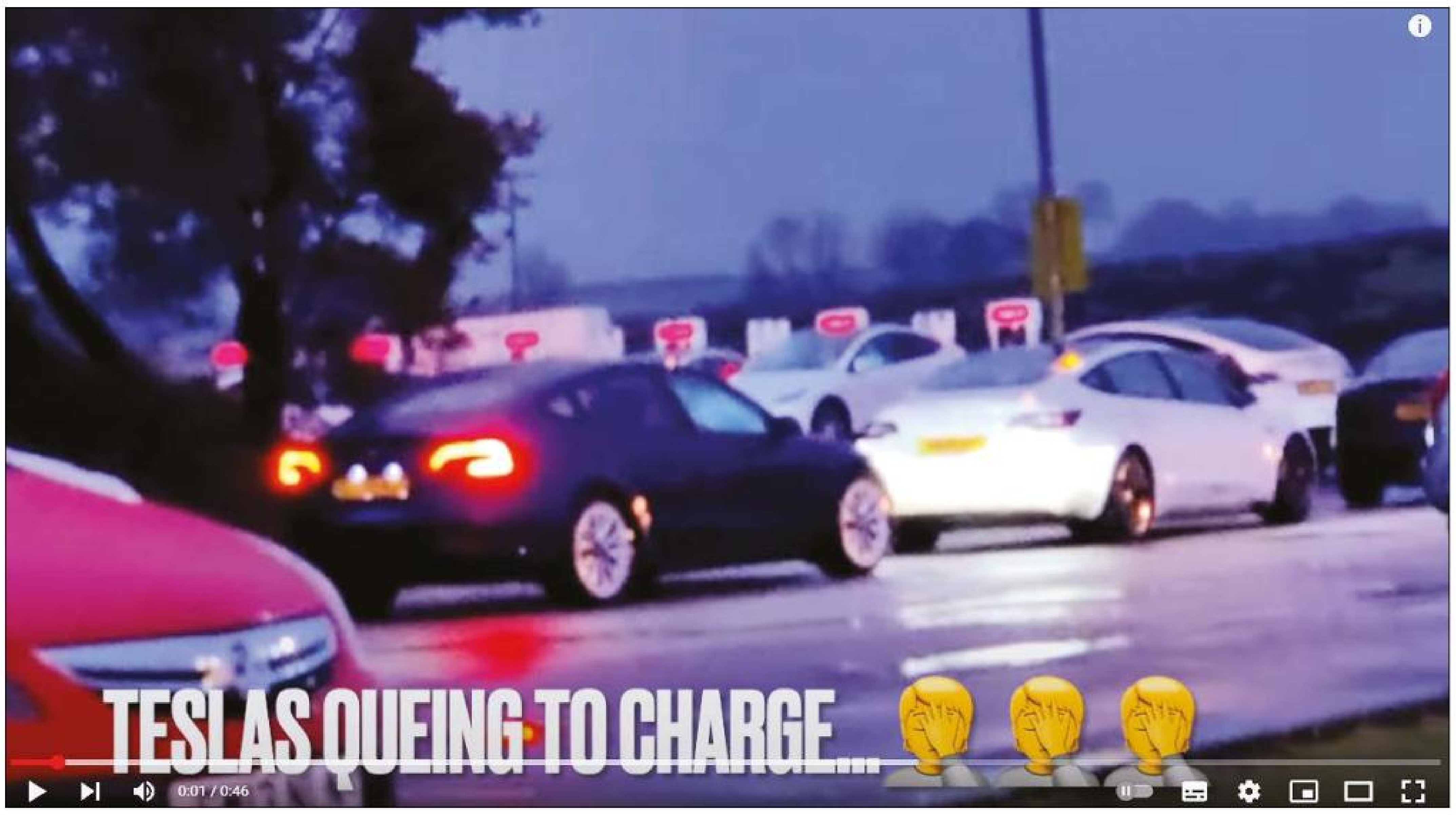

Driven to distraction: seventeen Tesla owners queue up to recharge in December (Image: YouTube/ Geoff Buys Cars).

Users of Windows 8.1 laptops and PCs are now on their own, as Microsoft stopped releasing security updates and fixes after 10 January 2023. Microsoft customer service for Windows 8.1 machines has also been withdrawn. There's still some life left in older systems like these, and it isn't entirely necessary to scrap them: anti-virus software such as AVG and Kaspersky Free will still run satisfactorily and safeguard against most online threats. The Firefox web browser will also function, though support for Windows 8.1 may end this year too. The final version of Google Chrome that runs under Windows 8.1 is v109, after which Windows 10+ is needed – older browsers will still run but will not be updated.

One alternative to a Windows laptop is a Chromebook, which runs Google's ChromeOS and needs cloud connectivity for storage. I liken them to using a tablet with a keyboard. They are touted as a safe and secure mobile solution that dispenses with the need for antivirus software, but what many users won't realise is that Chromebooks have an end-of-life expiry date too, after which software support and updates will cease. Chromebooks are manufactured by some well-known PC brands (eg, Asus, Acer, HP, Lenovo). You can check their Auto Update Expiration (AUE) date at **https://bit.ly/pe-mar23-ch1** and there's more general guidance published by Google at: **https://bit.ly/pe-mar23-ch2**

The number of Google apps and hardware products that have been shelved has now reached 280. The latest victims to find their way to the Google Graveyard include Google Stadia, YouTube Originals and $200 Google OnHub wireless routers. More at the website: **https://killedbygoogle.com**

Thrash metal

Just to prove that the author suffers his fair share of IT disasters, regular readers will know of his fondness for the Humax HDR-Fox T2 personal video recorder, a hard disk PVR that has a near-perfect GUI along with a searchable programme guide. It remains one of the writer's favourite bits of kit, despite poorly supporting a near-zero range of apps (BBC iPlayer is about all). Having diligently recorded various series and interesting-looking programmes to watch over the Christmas holidays, the author turned on the PVR only to be greeted by a hard disk error message: showing 0% free, the hard disk had crashed without warning, taking all the TV recordings with it.

It's simple enough to swap out the drive, but hard disks that are optimised for video applications are essential. The same criteria apply to NAS storage devices and CCTV surveillance recorders: ordinary desktop PC drives are made down to a price and aren't designed to withstand the constant thrashing of PVR or CCTV use, so the choice of suitable hard disks for video dwindles very rapidly. Currently, Western Digital 'Purple' or possibly Seagate 'Skyhawk' drives would be suitable, but these can cost £50 to £80 or more, and I also ruled out using a solid-state disk. Another solution was to search out new old stock (NOS) from older video disk drive ranges as befits my old video recorder. It wasn't long before a Seagate 'Pipeline' 1TB drive arrived at a cost of just £27. Job done, until the next time anyway.

That's all for this month's column. Readers will find an online summary with links on the *Net Work* blog of our website at: **www.electronpublishing.com** – see you next month!

The author can be reached at:
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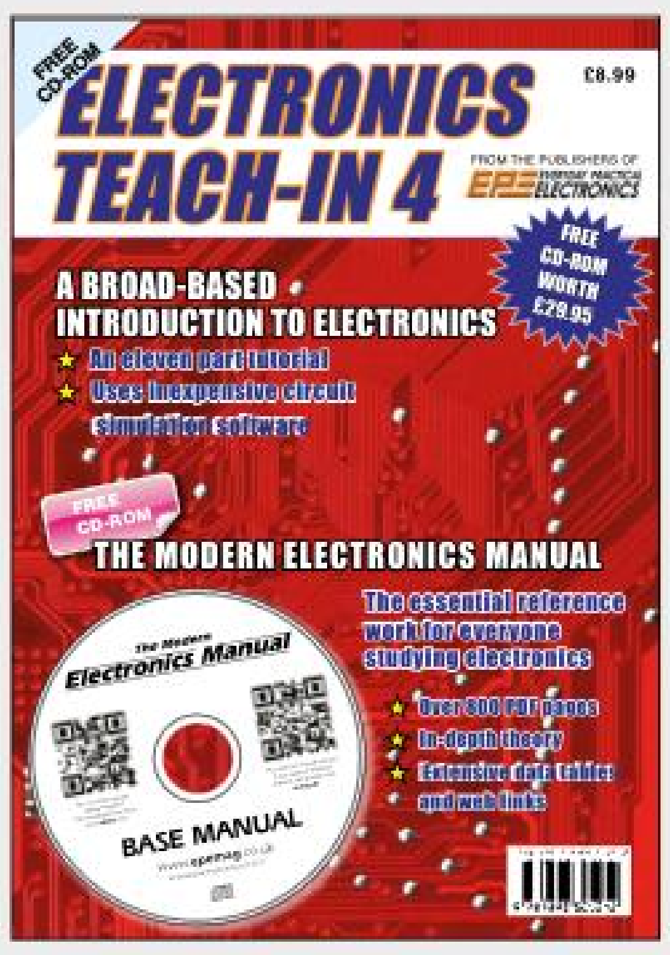

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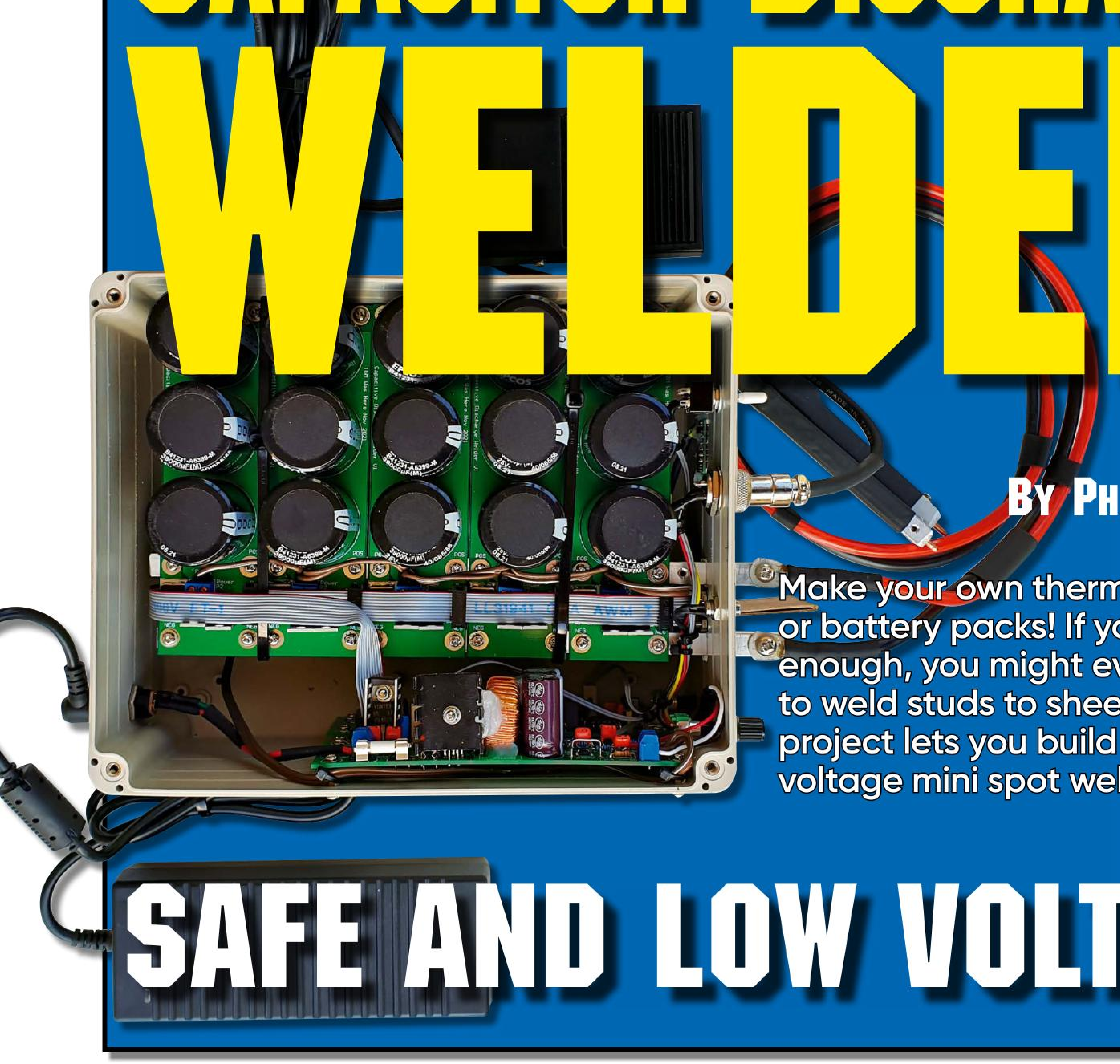
CAPACITOR DISCHARGE WELDER



PART 1

BY PHIL PROSSER

Make your own thermocouples or battery packs! If you're skilled enough, you might even be able to weld studs to sheet metal. This project lets you build a safe low-voltage mini spot welder.

SAFE AND LOW VOLTAGE

It's more expensive to buy thermocouples than to weld the tips of K-type thermocouple wire, available cheaply by the reel. And getting a custom-made battery pack for repair or for your project is also pricey. But the availability of used battery packs and individual cells means building custom batteries is a real option – as long as you have a way of welding tabs onto them.

Safely welding tabs to batteries is more challenging than you might think. You cannot use solder to make the joints as the metal does not 'wet' easily, and you need to get it dangerously hot to make the joint. This can damage the plastic insulators inside the battery, leading to catastrophic failure of the cell. Tabs on professionally made cells are welded on. This project allows you to do the same yourself.

Professional battery welders are generally ultrasonic welders, capacitor discharge welders or high-current spot welders. Most are way out of the ability for hobbyists to build. Capacitor discharge welders are at the lower end of the professional spectrum. These use energy stored in a bank of capacitors to deliver the weld energy to the workpiece.

A common characteristic of all battery tab welders is that they deliver an awful lot of energy (typically 100-200 joules, or more) to the connection in as short a period as possible.

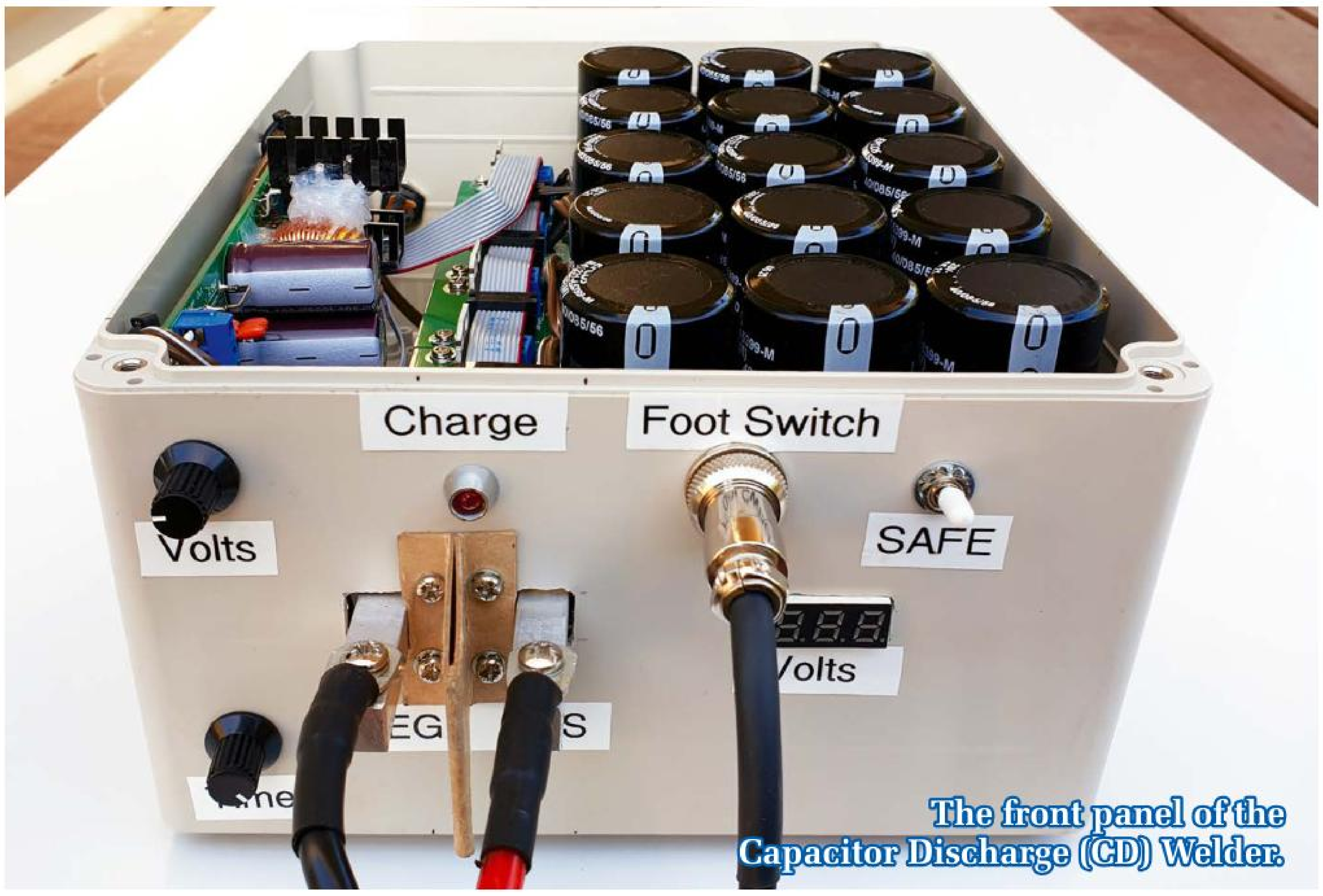
Safety warning

Capacitor Discharge Welding works by generating extremely high current pulses, and consequently, strong magnetic fields. Do not build or use this project if you have a pacemaker or similar sensitive device.

This device can generate sparks and heat. Users must wear appropriate personal protective equipment such as welding glasses that meets all relevant regulations and standards, and which provide mechanical and IR/UV protection.

Features and Specs

- **Weld energy:** adjustable, from a few joules up to 208-365J (depending on number and type of capacitors used)
- **Weld pulse duration:** 0.2-20ms with optional 0.1ms pre-pulse, 5ms before main pulse
- **Safety features:** trigger lockout during charging, foot switch triggering, kill switch
- **Capacitor charging:** 2A or 5A (selectable); switch-mode for high efficiency and fast charging
- **Welding leads:** 1m min length suggested, but can be customised
- **Power supply:** 24V DC, 2.5A minimum (6A+ recommended)



The front panel of the Capacitor Discharge (CD) Welder.

Options for DIY

One approach is to use a car battery or Li-ion cell with a beefy switching device. A very large SCR or FET is used to short the battery across the 'weld spot' for a short period.

While this can work, it has a hidden problem. The current is high enough to create a weld but not high enough to do it quickly. As a result, there can be a large 'heat-affected zone' and the weld quality varies depending on the health of your battery.

The other practical alternative is to roll your own *Capacitor Discharge Welder*. This is somewhat more expensive than using a big battery but provides more predictable results. Our design also gives you a lot of control of the weld energy and time.

Capacitor Discharge (CD) Welders

These do exactly what they say on the box. They comprise a capacitor bank that you charge up, and then electronically short it across the workpiece using one or more large FETs, SCRs or other very tough semiconductor switches. The weld is formed by resistive heating in the workpiece.

All of the energy that goes into the weld is from the capacitors. This provides you with certainty and repeatability about how much energy is delivered. The energy is also delivered very quickly, in a few milliseconds, which means the weld is done before heat conducts far from the joint.

The downside of this is that you need capacitor(s) that can take the abuse of massive discharge pulses, which can get expensive. The upside is that you can control the energy delivered to the weld in two dimensions, both by selecting the voltage the capacitor is charged to and by how long you turn the switches on.

Our approach

We want to do better than simply paralleling as many capacitors as we can find and using a giant SCR to switch them. Our goal is a project that allows you to choose the overall scale of the *Capacitor Discharge Welder*, allowing you to select the most cost-effective capacitors for your application.

While researching this, we came across Ian Hooper's work, which prompted the modular and scalable approach that is presented here, see: **https://bit.ly/pe-mar23-sw1**

Our design uses multiple Energy Storage boards which stack, allowing you to build a welder with the capacity you need. A separate Power Supply Module allows you to control the voltage and provides a constant charge current to the capacitor bank. A Controller Module enables you to program the weld pulse width you want.

These features are typically found on professional kit. Our charger is based on a switch-mode regulator, which means that we can control the current charging the capacitors without using a resistor or linear regulator – both of which would otherwise get stinking hot!

With the recommended 10 Energy Storage Modules (ESMs), we have 1.2 farads of storage, which we can charge to about 2-25V DC. The pulse width can be varied from under one millisecond through to 20ms.

Hold up there, Dr Evil! Are we seriously talking about shorting a 1.2F capacitor across the weld joint? At just 25V, this is 375J! Let's think this through; there are safety issues to be considered here!

We have intentionally used a maximum charge voltage of 25V, which is well below the Extra Low Voltage threshold and reduces voltage-related safety hazards to operators. We use a 24V DC 6A plug pack to charge it up, so no mains wiring is involved.

But the *Capacitor Discharge Welder* stores an awful lot of energy. This warrants great caution in use, with the risk of burns and arcing. Safety must be at the front of your thinking when using it.

From a design perspective, we seek to minimise the risk of inadvertent firing, ie, 'uncontrolled output', including by using:

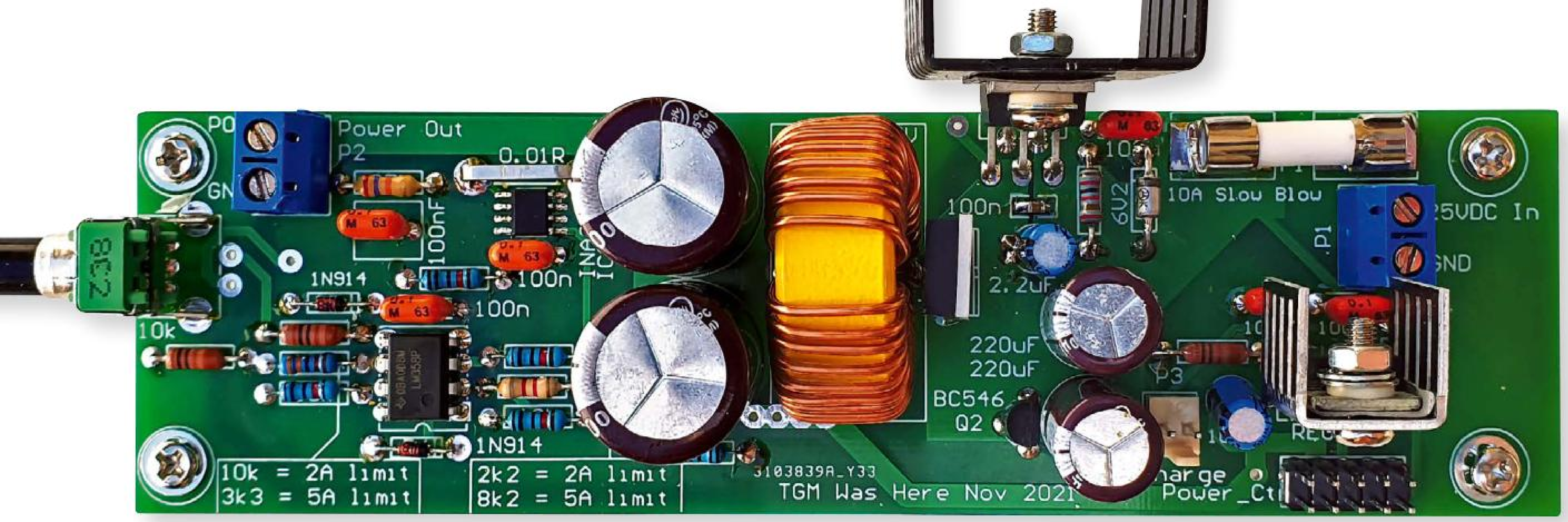
- A fire button that only enables the output for a few milliseconds, minimising the risk of creating an arc when placing the weld probes on the workpiece.
- An interlock stopping firing during charging, avoiding multiple shots.
- An enable/kill switch.
- A footswitch to fire the Welder while keeping both hands free.

Operating principle

The basic idea behind the *Capacitor Discharge Welder* is shown in Fig.1. This simple welder model consists of the capacitors, connections and MOSFETs. Note that the MOSFETs pull the negative lead down to ground potential but are 'flipped' in this figure for clarity.

This seems simple enough, but the question at the forefront of our minds is: will the capacitors and MOSFETs survive the very high currents involved, especially on a repetitive basis? To do this, we need to determine what the peak current is likely to be and how it decays over time. To assess this we need a model of all the parts involved, starting with the capacitors and the boards on which they mount.

Most of the recommended capacitors have an ESR (equivalent series resistance) specification close to 20mΩ, so we'll start with that figure. For the capacitor closest to the 'output' end of the board, we calculate a trace resistance (both positive and negative) of 0.5mΩ,



The finished Power Supply Module used in the Capacitor Discharge Welder. Its main job is to charge the capacitor bank, but it also provides power to the rest of the circuitry.

giving 20.5mΩ. The other capacitors are a bit further away, so we calculate figures of 21.27mΩ and 22.05mΩ.

These three capacitors are in parallel, so we can calculate their combined source resistance as 20.5mΩ || 21.27mΩ || 22.05mΩ = 7.08mΩ. Then we add the MOSFET on-resistance (1.7mΩ || 1.7mΩ = 0.85mΩ), the PCB track resistance from the MOSFETs to the bus bar and the resistance of the connections to the bus bars, giving us a total of 8.33mΩ per module.

We've paralleled ten of these modules, giving an overall source impedance of 0.83mΩ (10% of the figure above). To this, we must add the resistance of the bus bars (around 0.1mΩ each), the welding tips (a total of about 0.5mΩ) and then the welding cables. We're using 1m-long cables with 7.1mm^2 cross-sectional area for a figure of 2.6mΩ each, dominating the final source resistance value, which is 7.53mΩ.

Given this, what is the maximum current we can deliver? Will the FETs even survive?

Of course, the workpiece will never be 0Ω. With reasonably pointy probes welding a 0.15mm-thick nickel strip, this will be more like 5mΩ. But we will conservatively use a value of zero for our calculations.

This tells us that it would be a terrible idea to fire the welder with the bus bars shorted. If we omit the lead resistance, the load will be 1.5mΩ plus whatever shorts the bars. This gives a worst-case current of 16,000A or 800A per MOSFET, which is right up against their 1ms safe operating area (SOA) curve. The MOSFETs might survive this, but whatever shorts the bus bars might not!

Under 'normal' operation, the worst-case current will be 3300A with the 1m leads perfectly shorted. This is 166A peak per MOSFET (two per module) for a few milliseconds. The specified devices are rated to handle 192A continuously, and their SOA is 600A for 10ms, giving us a reasonable safety margin.

Under more realistic conditions, and with a 5mΩ workpiece, the maximum current will be 25V ÷ (7.53mΩ + 5mΩ) = approximately 2000A. This can be controlled by reducing the operating voltage and pulse width.

This analysis might seem over the top – but a *CD Welder* is quite a device! I was just a little intimidated the first time I fired it in anger!

Major parts

The resulting *CD Welder* block diagram is shown in Fig.2. We will discuss each part and explain some of the challenges they present.

1) Power Supply Module

The problem with charging a 1.2F capacitor is that to any regular power supply, it looks like a short circuit. Also, when fired, the *CD Welder* power supply is shorted out. It must be able to tolerate this on a repetitive, long-term basis.

A linear regulator might do the job, but it would face several problems. For a start, it would get hot! Also, if we use a 5Ω resistor to limit the charging current, the initial current will be 5A, but it will not fully charge the capacitor for close to 20 seconds. We determine this by solving the equation $V_{CAP} = V_{IN} \times (1 - e^{-t \div (RC)})$ for t, with a value of V_{CAP} close to V_{IN}.

This convinced us to instead use a switch-mode regulator with a 5A (or 2A) constant current output. This only dissipates a few watts even when running flat out. An equation for calculating the charge time is C = Q ÷ V, where C is in farads, Q in coulombs and V in volts. Differentiating and rearranging this equation gives us dV/dt = I ÷ C. With I = 5A and C = 1.17F, dV/dt is 4.3V per second.

Note that you can also determine your actual capacitor bank capacity using this equation by measuring its charge rate and then solving for C.

2) Control Module

We need a way to trigger all the capacitors to dump their charge into the welding probes simultaneously, for a defined period. We have used the venerable NE555 timer IC to do this. The Controller needs to work in a tough electrical environment, so using a 'bulletproof' chip in a simple configuration is the way to go.

We hope you are picking up on the attention we are paying to EMI/EMC and the currents involved here!

Professional controllers offer a 'two-pulse weld' mode. The initial pulse cleans the surface between the parts and the second pulse makes the weld. This feature is easy to provide, so we did. Three timer ICs generate the initial pulse, then a delay, then the second pulse.

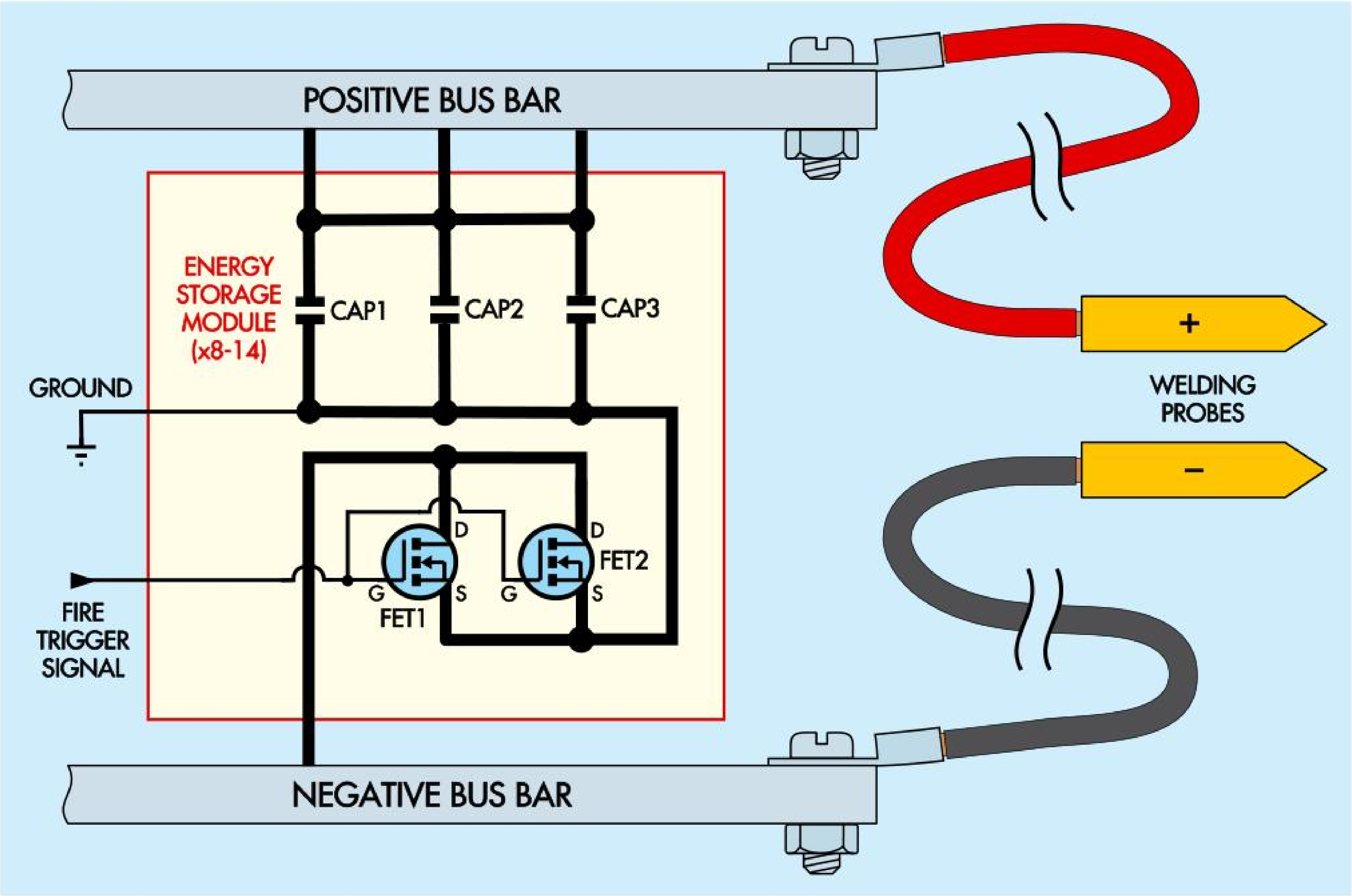
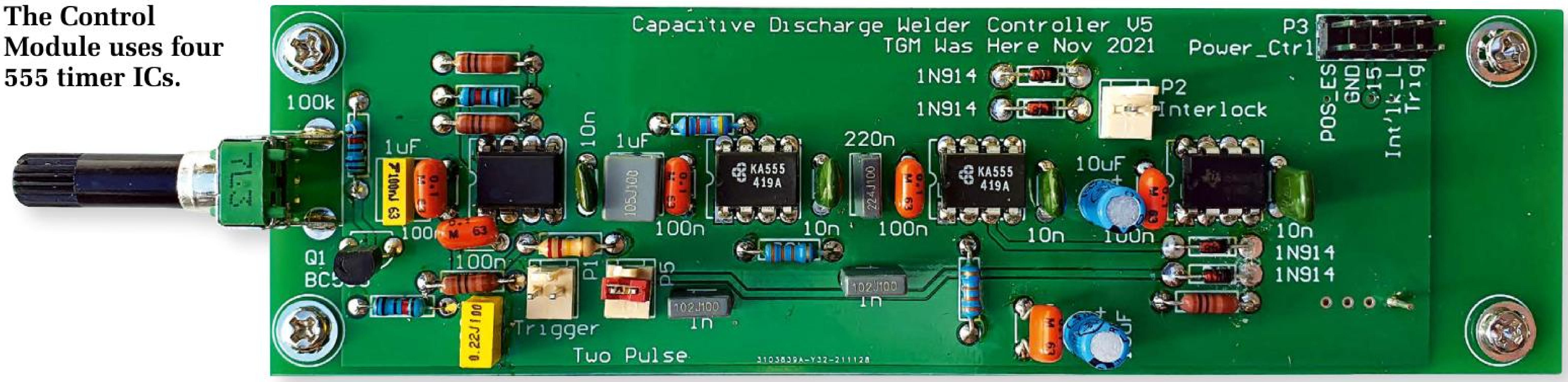


Fig.1: the basic concept of the Capacitor Discharge Welder is a capacitor bank of around 30 capacitors in parallel that are charged up and then connected across the heavy welding leads when the MOSFETs are switched on. The trick is making sure everything survives this process as over 1000A can flow!

The Control Module uses four 555 timer ICs.



Energy Storage Module (ESM)

The Storage Module takes inspiration from Ian Hooper's work (mentioned above), then extends this to provide us more control over the switching and increases robustness to back-EMF.

This ESM accepts 10mm lead pitch (spacing) caps with a diameter up to 35mm. This provides you with many options for sourcing these expensive parts. We recommend you use caps of known provenance from the likes of Farnell, Mouser or Digi-Key. Online prices that seem too good to resist are usually a bad choice with capacitors.

The ESMs bolt to bus bars, allowing paralleling of an arbitrary number of modules. They provide fast switching using two onboard high-current MOSFETs and a dedicated FET driver. They also have an inbuilt flyback diode to protect against the back-EMF and are easy to build, wire up and service.

Switching really high currents is not a simple thing to do. By switching each module rather than the whole bank, we can 'divide and conquer'.

The recommended bank of 30 capacitors on 10 ESMs will each see currents in the region of 50A per capacitor every time a weld is made. The RMS ripple current rating of the recommended capacitors is about 10A, but the limiting factor for aluminium electrolytic capacitors is heating. The average current is very low because of our low pulse rate, so the I^2R losses are insignificant.

Capacitor choice

The capacitors for a CD welder are the main expense. During the development of this project, we spent much time investigating the trade-offs in the total energy stored, capacitor voltage rating and the safety and robustness of the switching system.

The choice has also been complicated by parts availability. The 2021-2022 drought for electronic components (especially semiconductors) is making our life extremely difficult, as even seemingly ordinary parts are hard to get. Perhaps surprisingly, this includes capacitors, especially large electrolytics.

Luckily, there is a range of choices you can make in selecting your capacitors. For 25V-rated capacitors, we recommend that you aim for a total capacitance of no less than 1F. Ideally, hit the 1.2F mark for some spare capacity. Table 1 shows some good choices here.

If you choose to use 16V capacitors, you can probably save a few pounds. In this case, aim for a total capacitance of no less than 1.5F and ideally 2F if you want a bit of extra margin. All of the options shown in Table 2 will total around £100 or so.

Remember that the welding process is about the energy delivered to the weld – the actual capacitance is a means to an end, and using a higher voltage makes this easier. You will find availability and price can be something of a 'head-scratcher', and we are sure you will have hours of 'fun' working out your best value for money!

Probably the only thing we would advise against is using much larger capacitor values than we recommend – our models show that for the values in the tables above, it should be OK, but much more capacitance on a module could lead to MOSFET failure.

So how much energy do we need? We found about 130J was sufficient for the tabs we welded. We're confident a welder with 200J total storage would suit our needs. The recommended design can deliver 370J, which would definitely provide margin throughout its life.

Circuit details

Fig.3 is the circuit diagram of the Power Supply module. The regulator used is an MC34167 device, a switch-mode regulator operating at 71kHz. It is operated in a buck (step-down) configuration, using a 220µH filter/energy storage coil and 15A schottky flyback diode with two 1000µF smoothing capacitors on the output.

These will help reduce radiated EMI during charging, but the >1000A pulses will still play havoc with any sensitive electrical device nearby.

To turn a voltage regulator into a current source, we need to sense the output current and convert this into a voltage as feedback. This is done by the INA282 shunt monitor IC, IC2, with a 10mΩ series shunt. The INA282 has a gain of 50 times, so its pin 5 output delivers 500mV/A. This is further amplified by a factor of about 6.5 by op amp IC3a, resulting in 2.8V/A to the feedback pin (pin 1) of IC1.

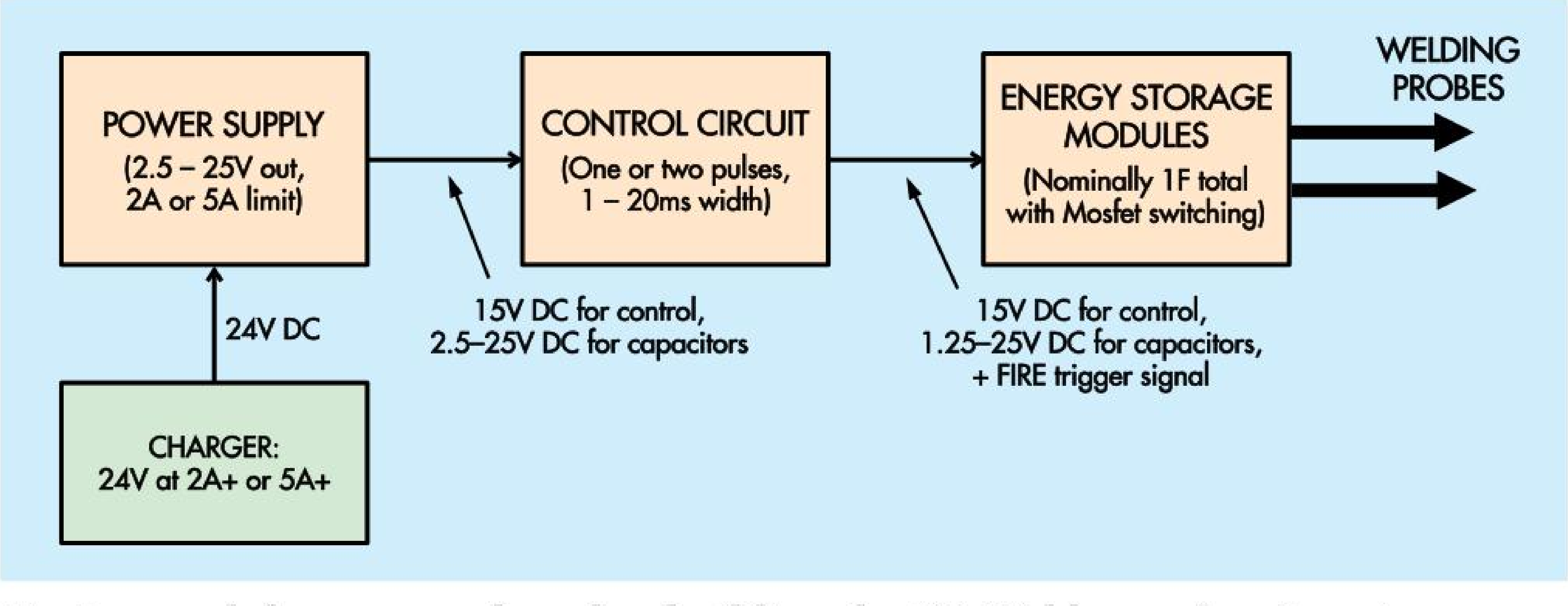
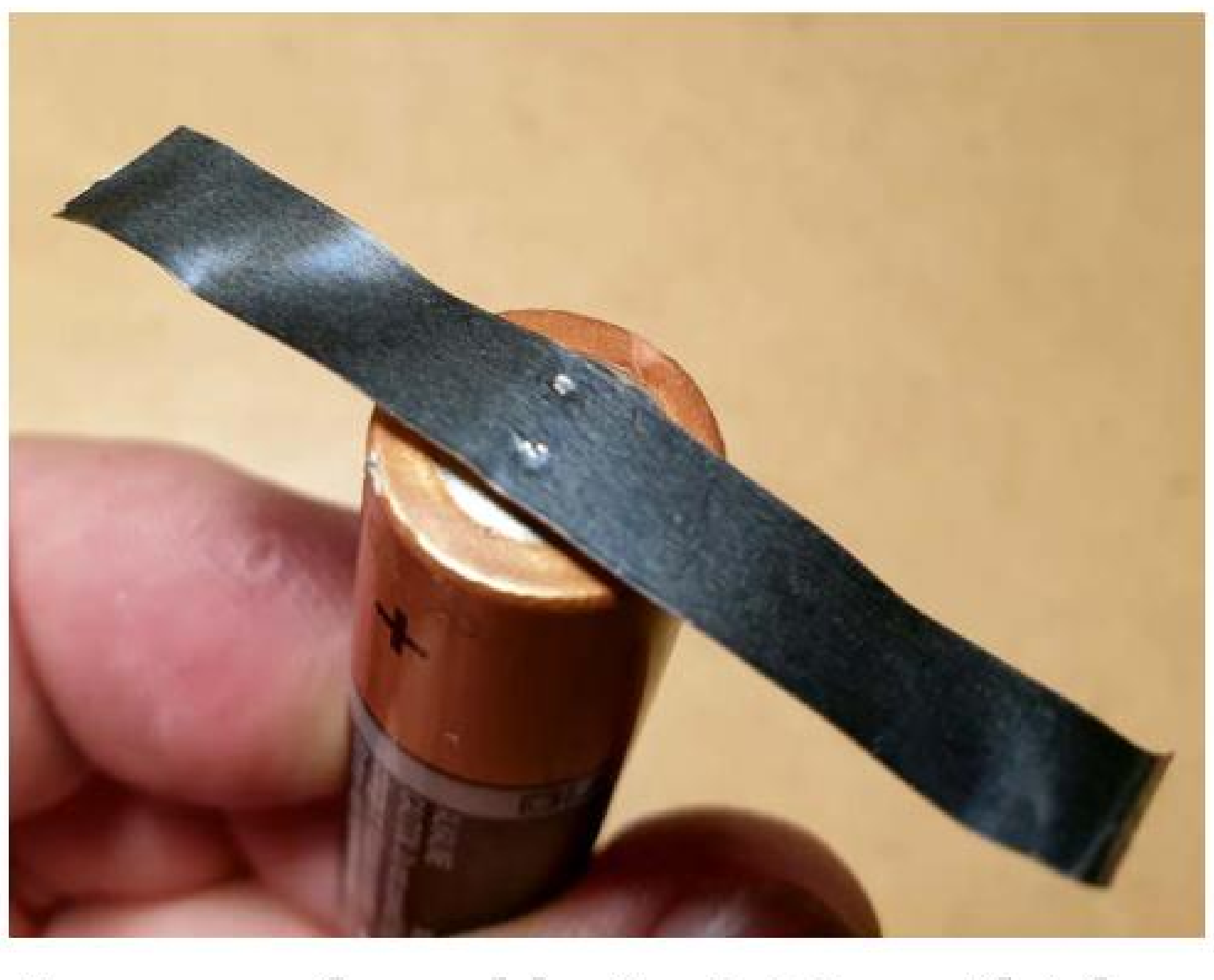

POWER SUPPLY
(2.5 – 25V out, 2A or 5A limit)
CONTROL CIRCUIT
(One or two pulses, 1 – 20ms width)
ENERGY STORAGE MODULES
(Nominally 1F total with Mosfet switching)
WELDING PROBES
24V DC
15V DC for control, 2.5–25V DC for capacitors
15V DC for control, 1.25–25V DC for capacitors, + FIRE trigger signal
CHARGER: 24V at 2A+ or 5A+

Fig.2: a modular approach makes building the CD Welder easier. A mains power 'brick' is fed into the power supply, which provides a constant current to charge the capacitor bank. Said bank comprises eight or more Energy Storage Modules (ESMs – 10 in our case) connected in parallel using bus bars. The control circuit provides the timing and the ability to trigger all the ESMs to dump their charge into the welding probes simultaneously.



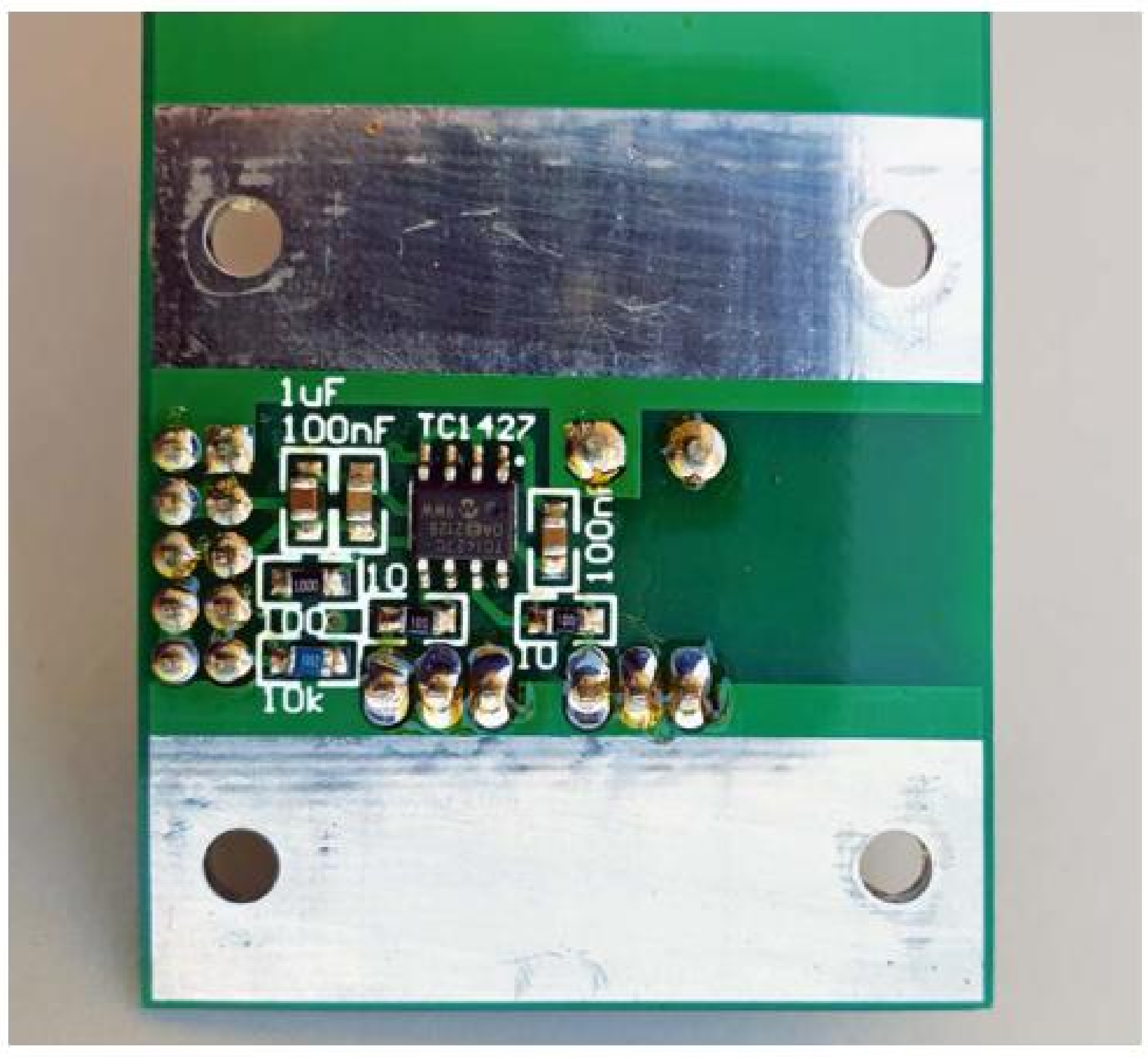
An example weld of a 0.12mm-thick strip of nickel at 15V with a 20ms weld time onto an AA cell used for testing. The result was that the tab could not be pulled off with any reasonable amount of force applied.

Table 1 – suitable 25V-rated capacitors (M=Mouser, DK=Digi-Key)

Capacitor value	# ESMs	Caps per ESM	Total capacity	Energy stored	Suitable parts
56,000µF	8-10	2	0.9-1.1F	280-350J	**DK:** 338-3866-ND
39,000µF	8-10	3	0.9-1.17F	300-365J	**M:** B41231A5399M002 **DK:** 338-3743-ND
33,000µF	10	3	1F	310J	**M:** SLPX333M025E9P3 | B41231A5339M000 | 380LX333M025K052 **DK:** 338-1613-ND
22,000µF	14	3	0.92F	288J	**M:** SLP223M025H5P3 | 380LX223M025J052 **DK:** 495-6159-ND | 338-4172-ND | 338-2431-ND

Table 2 – suitable 16V-rated capacitors (M=Mouser, DK=Digi-Key)

Capacitor value	# ESMs	Caps per ESM	Total capacity	Energy stored	Suitable parts
68,000µF	12-14	2	1.6-1.9F	208-243J	**M:** B41231A4689M000 | 380LX683M016A052 **DK:** 495-6141-ND | 338-2273-ND
56,000µF	10-12	3	1.7-2.0F	220-256J	**M:** B41231A4569M000 | SLPX563M016H4P3
47,000µF	14	3	2F	256J	**M:** B41231B4479M000 **DK:** 338-2458-ND | 338-2318-ND
39,000µF	14	3	1.6F	210J	**M:** B41231A4339M000 | 380LX393M016A032 | 16USG39000MEFCSN25X50 **DK:** 338-2261-ND



All the SMD components are located on the underside of the Energy Storage Module (ESM).

If pin 1 of IC1 is lower than 5.05V, the regulator increases its output. Similarly, if the input is higher than 5.05V, the output duty cycle and thus voltage/current is reduced.

So with 2.8V/A, we get an output current close to 1.8A (5.05V ÷ 2.8V/A). The 5A version of the circuit changes two resistors (values shown in green), setting the gain of IC3a to 2.2 times, so its output is 1.1V/A and therefore, the current limit is around 4.6A (5.05V ÷ 1.1V/A).

So that the capacitor charging stops when it reaches the desired voltage, the output voltage is applied to potentiometer VR1 via a 27kΩ resistor and the reduced voltage at its wiper is buffered by op amp IC3b. This is fed into the 'current sense' input of IC3a (pin 3) via diode D3, which 'ORs' these voltages together.

This means that when the output voltage is lower than the set limit, the circuit operates as a constant-current source. When the output voltage reaches the programmed limit, the voltage from VR1 exceeds the current sense voltage, and regulation is now voltage-controlled.

When in current-limit mode, we switch on the CHARGE LED connected across CON3. At the same time pin 7 of CON4 is pulled low, which acts as an interlock in the controller circuit on the 'fire' switch. This is used to stop the user from making a weld before the capacitors are fully charged.

Controller circuit

The controller circuit is shown in Fig.4. Three NE555 devices, IC4-IC6, are set up as monostable (single-shot) pulse generators in series (output to trigger input), with a fourth (IC7) acting as a high-current buffer. This allows us to generate a first pulse, a delay and a second pulse. The main weld pulse is controllable using 100kΩ potentiometer VR2, variable from under 1ms to about 20ms.

GND
POS
Power P2
NEG
P1
POS
40/085/56
TGM Was Here Nov 2021

About 10 of these ESMs are joined together to form a capacitor bank for the CD Welder.

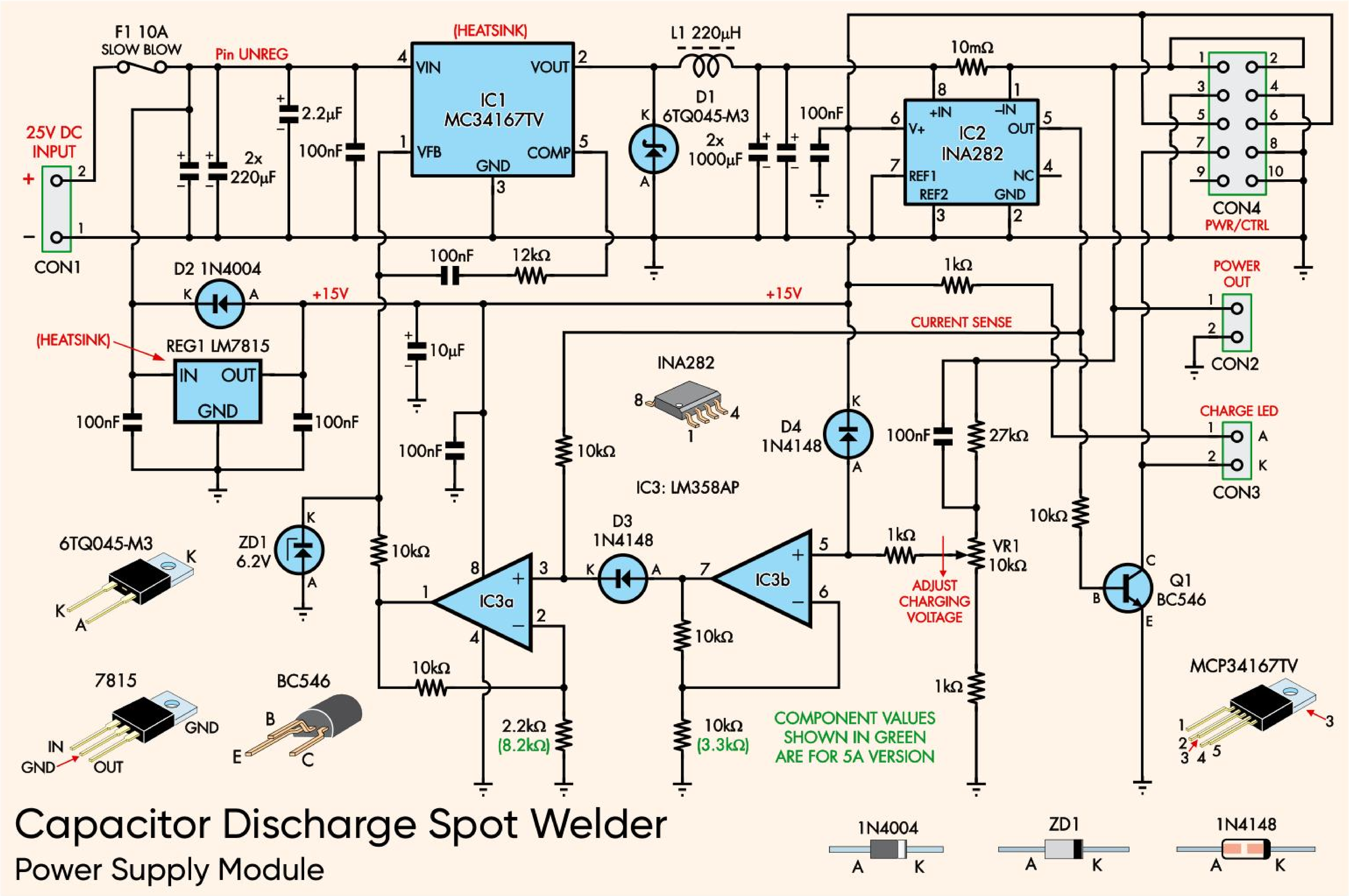

F1 10A
SLOW BLOW
Pin UNREG
25V DC
INPUT
CON1
2x
220µF
2.2µF
100nF
(HEATSINK)
IC1
MC34167TV
VIN
VOUT
VFB
COMP
GND
L1 220µH
D1
6TQ045-M3
2x
1000µF
100nF
10mΩ
IC2
INA282
+IN
–IN
V+
OUT
REF1
REF2
NC
GND
CON4
PWR/CTRL
POWER
OUT
CON2
CHARGE LED
CON3
D2 1N4004
+15V
REG1 LM7815
IN
OUT
GND
100nF
12kΩ
10µF
1kΩ
CURRENT SENSE
INA282
IC3: LM358AP
D4
1N4148
27kΩ
10kΩ
ZD1
6.2V
IC3a
D3
1N4148
IC3b
1kΩ
VR1
10kΩ
ADJUST
CHARGING
VOLTAGE
Q1
BC546
2.2kΩ
(8.2kΩ)
10kΩ
(3.3kΩ)
COMPONENT VALUES
SHOWN IN GREEN
ARE FOR 5A VERSION
6TQ045-M3
7815
BC546
MCP34167TV
1N4004
ZD1
1N4148
Capacitor Discharge Spot Welder
Power Supply Module

Fig.3: the Power Supply circuit derives a 15V rail to run the remainder of the circuit from the 24V DC input using a simple linear regulator. The rest of the components form the constant-current switch-mode step-down regulator. It's based around switching regulator IC1 with shunt monitor IC2 and op amp IC3 used to make it deliver a fixed current until the capacitor bank reaches the fully charged voltage selected using potentiometer VR1.

If the 'two-pulse' switch connected to CON8 is open, only the output trigger pulse from IC6 is fed (via diode D6) to timer IC7, so a single trigger pulse goes to pin 9 of CON7. If that switch is closed, the outputs pulse from both IC4 and IC6 result in a trigger pulse. Timer IC5 provides the delay between these pulses.

We chose the NE555 as a driver because it can operate from 15V, can deliver 200mA, has a fast rise time (300ns) and can easily drive our TRIGGER bus. This switches all the energy storage modules simultaneously.

The 'fire' input to the Controller, connected to CON5, is a switch to ground. We have included PNP transistor Q2 to inhibit the input while the capacitors are charging. When the INHIBIT line from pin 7 of CON7 is low, Q2 is on and it holds the trigger input feeding pin 2 of IC4 high. The 1µF capacitor between its base and the 15V rail avoids noise coupled into the INHIBIT line from causing problems.

Similarly, if the pins of the ENABLE header (CON6) are shorted (eg, via a switch), this will prevent triggering by switching on Q2 via diode D8.

The control interface PCB design uses tightly-packed surface-mounted components to increase its EMI robustness and avoid false triggering.

ESM circuit

This is shown in Fig.5. There isn't much to it – mainly just the three (or two) storage capacitors, two MOSFETs and the dual MOSFET driver, IC8.

We explained earlier why we are using the very high-current IRFB7430 FETs. These must be tightly controlled in terms of switching time, and switch on and off cleanly. The TC1427 MOSFET driver can deliver up to 1.2A into the FET gates, switching them in 25ns. It has input hysteresis, which will help our robustness to noise. The alternative, pin-compatible IX4340NE in the parts list can deliver an even higher current of 5A for very rapid switching indeed.

IC8's inputs are connected to the TRIGGER bus from the NE555 which has a 15V swing, again seeking to avoid false switching due to noise. By driving all Energy Store Modules with the common Trigger signal, we aim to ensure that all Energy Store Modules are switched on and off at as close to the same time as possible.

The Welder in action

Scope 1 (overleaf) is a digital oscilloscope capture showing the voltage

After building your CD Welder. It's useful to make some test welds on scrap metal to get an idea of how much voltage and time is needed to form a decent weld. Too much energy will burn and distort the metal, and even blow holes in it, as shown on the left tab. On the right, you can see that we managed to weld the tab to the can without destroying it.

Parts List – Capacitor Discharge Welder

1 250 x 200 x 130mm ABS enclosure [**Altronics H0364A**]
1 Power Supply module (see below)
1 Controller module (see below)
8-14 Energy Storage modules (see below and Tables 1-2)
1 82Ω 5W 10% resistor (for testing)
1 0.27Ω 5W 10% resistor (for testing)
1 panel-mount digital voltmeter (**optional**; to display selected voltage) [**eBay, AliExpress etc**]

Switches/connectors
3 two-way polarised header plugs with pins (foot switch, enable, charge) [**3 x Altronics P5472 + 6 x P5470A or 3 x Jaycar HM3402**]
12 10-way IDC line sockets [**Altronics P5310 or Jaycar PS0984**]
1 3-pin circular microphone inline socket (for footswitch cable) [**Altronics P0949**]
1 3-pin circular microphone chassis-mount connector (for footswitch) [**Altronics P0954**]
1 footswitch (trigger) [**Altronics S2700 or Jaycar SP0760**]
1 miniature chassis-mount SPDT toggle switch (two pulse select) [**Altronics S1310 or Jaycar ST0555**]

Wire/cable/etc
1 1m length of 8AWG red power wire (welding lead)
1 1m length of 8AWG black power wire (welding lead)
1 200mm length of 17AWG red tinned extra-heavy-duty hookup wire [**Altronics W2283**]
1 200mm length of 17AWG green tinned extra-heavy-duty hookup wire [**Altronics W2285**]
1 1m length of twin speaker cable, rated to handle at least 5A
1 2m length of two-core heavy-duty microphone cable (footswitch lead) [**Altronics W3028**]
1 1m length of 10-way ribbon cable
1 100mm length of 20mm diameter heatshrink tubing (for welding cables)
1 300mm length of 12.7mm diameter heatshrink tubing (for handles)
1 100mm length of 10mm diameter heatshrink tubing (for welding cable lugs)

Hardware
2 260mm length of 10 x 10mm square aluminium bar (bus bars)
2 100mm length of 10 x 10mm square aluminium bar (handles)
6 M4 x 10mm panhead machine screws (for handles and welding connections)
2 M4 shakeproof washers (for welding connections)
10 M3 x 10mm tapped spacers (for joining modules together)
4 M3 x 16mm panhead machine screws (for Presspahn shield)
40 M3 x 6mm panhead machine screws (module connections)
44 M3 shakeproof washers
2 6mm heavy duty eyelet crimp lugs for 7/8AWG wire [**Altronics H1757B**]
1 60 x 40mm sheet of Presspahn or similar insulating material [**Jaycar HG9985**]

Power Supply (one needed)
1 double-sided PCB coded 29103221, 150 x 42.5mm
1 220μH 5A toroidal inductor (L1) [**Altronics L6625 or Mouser 542-2316-V-RC / 542-2200HT-151V-RC**]
1 10kΩ 9mm linear right-angle potentiometer with plastic shaft (VR1) [**Altronics R1906**]
1 10A M205 slow-blow fuse (F1)
2 PCB-mount M205 fuse clips (F1)
2 2-way mini terminal blocks, 5/5.08mm pitch (CON1, CON2)
1 2-way polarised header, 2.54mm pitch (CON3)
1 2x5 pin header (CON4)
1 micro-U TO-220 heatsink (for REG1) [**Altronics H0627**]
1 mini-U TO-220 heatsink (for IC1) [**Altronics H0625, Jaycar HH8504**]
2 TO-220 insulating kits with silicone washers and plastic bushes (for REG1 and IC1)
2 M3 x 10-16mm panhead machine screws, shakeproof washers and nuts (for mounting heatsinks)
4 M3 tapped spacers
8 M3 x 6mm panhead machine screws and shakeproof washers
1 PCB pin (**optional**)

Semiconductors
1 MC34167TV or MC33167TV 0-40V 5A integrated buck regulator, TO-220-5 (IC1)
1 INA282AIDR bidirectional current shunt monitor, SOIC-8 (IC2)
1 LM358 dual single-supply op amp, DIP-8 (IC3)
1 LM7815 15V 1A linear regulator, TO-220 (REG1)
1 BC546 65V 100mA NPN transistor, TO-92 (Q1)
1 6.2V 400mW zener diode (ZD1) [**1N753, Altronics Z0318**]
1 6TQ045-M3 45V 6A schottky diode, TO-220AC (D1)
1 1N4004 400V 1A diode (D2)
2 1N4148 75V 150mA signal diodes (D3, D4)

Capacitors
2 1000μF 50V low-ESR electrolytic
2 220μF 50V low-ESR electrolytic
1 10μF 50V electrolytic
1 2.2μF 50V X7R multi-layer ceramic
6 100nF 50V X7R multi-layer ceramic
1 100nF 50V SMD M2012/0805 size multi-layer ceramic

Resistors *(all 0.25W 1% metal film unless stated)*
1 27kΩ
1 12kΩ
6 10kΩ
1 8.2kΩ (for 5A version)
1 3.3kΩ (for 5A version)
1 2.2kΩ
3 1kΩ
1 0.01Ω (10mΩ) 1% 1W shunt [**Mouser OAR1R010JLF**]

across the capacitor bank just after the Welder is triggered. In this test, only one ESM has been connected. You can see the sudden drop in voltage to around 5V over about 20ms when the weld is made, and the recharge, which takes a few hundred milliseconds.

Measurements taken from this screen capture let us calculate the total capacitance and the weld current using the formula $C = Q \div V$ introduced earlier, along with $C = I \div (dV/dt)$. We know the charge current I is close to 2A. We measure a 10.5V increase in voltage over 616ms, so:

Controller (one needed)

1 double-sided PCB coded 29103222, 150 x 42.5mm
1 100kΩ 9mm linear right-angle potentiometer with plastic shaft (VR2) **[Altronics R1908]**
3 2-way polarised headers, 2.54mm pitch (CON5, CON6, CON8)
1 2x5 pin header (CON7)
1 jumper shunt (**optional**)

Semiconductors
4 LM555 timer ICs, DIP-8 (IC4-IC7)
1 BC556, BC557, BC558 or BC559 30V 100mA PNP transistor, TO-92 (Q2)
4 1N4148 75V 150mA signal diodes (D5-D8)

Capacitors
2 10µF 50V electrolytic
1 1µF 63V MKT
1 1µF 50V multi-layer ceramic
1 220nF 63V MKT
1 220nF 50V multi-layer ceramic
7 100nF 63V MKT
4 10nF 63V MKT
2 1nF 63V MKT

Resistors *(all 0.25W 1% metal film)*
1 220kΩ
2 33kΩ
3 10kΩ
1 4.7kΩ
4 1kΩ

Energy Storage module (parts for one module)

1 double-sided PCB coded 29103223, 150 x 42.5mm
1 2x5 pin header (CON9)
1 2-way mini terminal blocks, 5/5.08mm pitch (CON10)
4 M3 tapped spacers
8 M3 x 6mm panhead machine screws and shakeproof washers

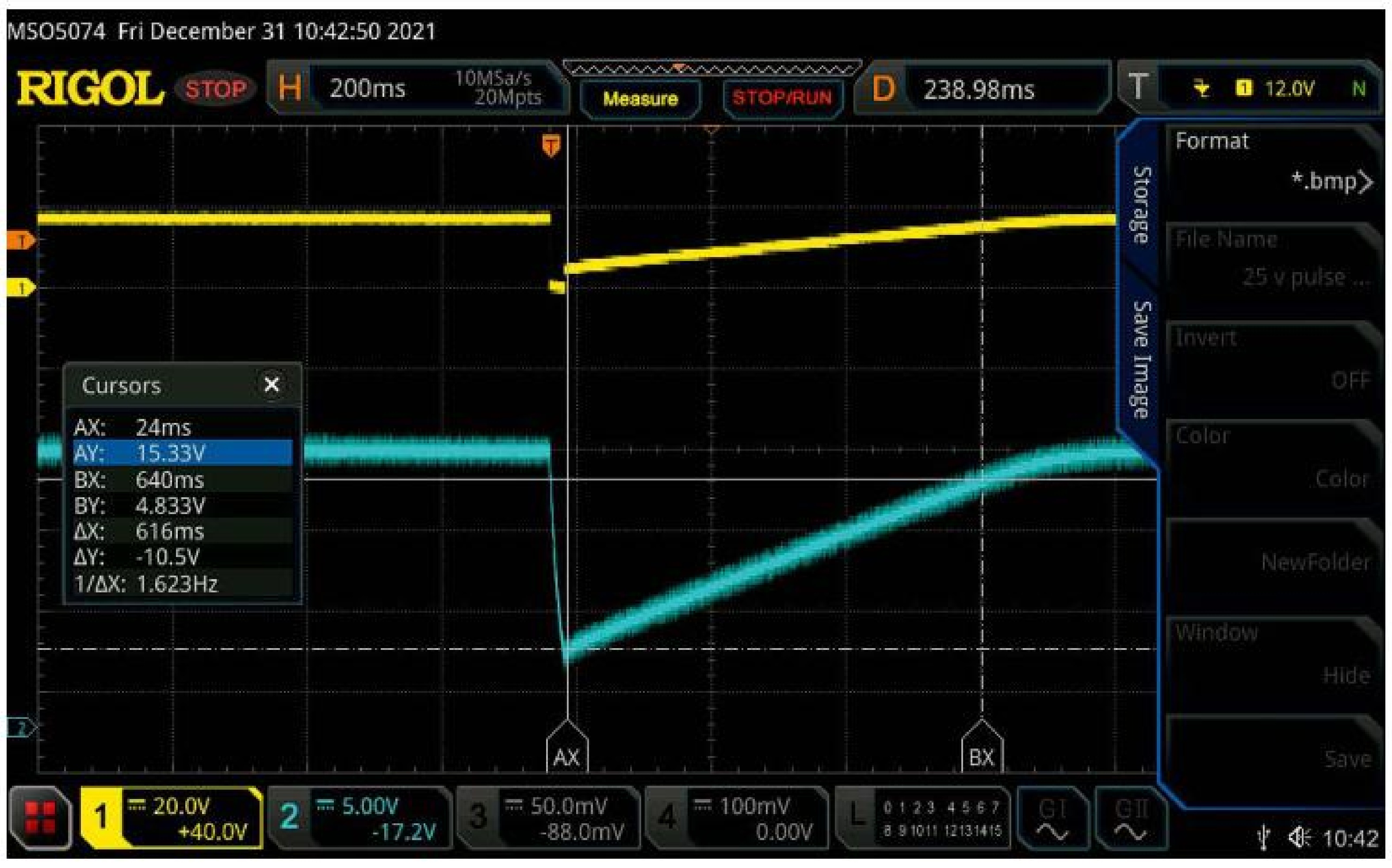
Semiconductors
1 TC1427COA713 or IX4340NE dual low-side MOSFET driver, SOIC-8 (IC8)
2 IRFB7430PbF 40V 409A MOSFETs, TO-220 (Q3, Q4)
1 RFN20NS3SFHTL 20A 350V fast recovery SMD diode or similar, TO-263S-3/D2PAK (D9)
1 red LED (LED1)

Capacitors
3 39mF 25V high ripple current snap-in capacitors, 10mm lead spacing, 35mm diameter **[Mouser B41231A5399M002 or Digi-Key 338-3743-ND or alternatives as per Table 1 or 2]**
1 1µF 16V X7R ceramic, SMD M2012/0805 size
2 100nF 50V X7R ceramic, SMD M2012/0805 size

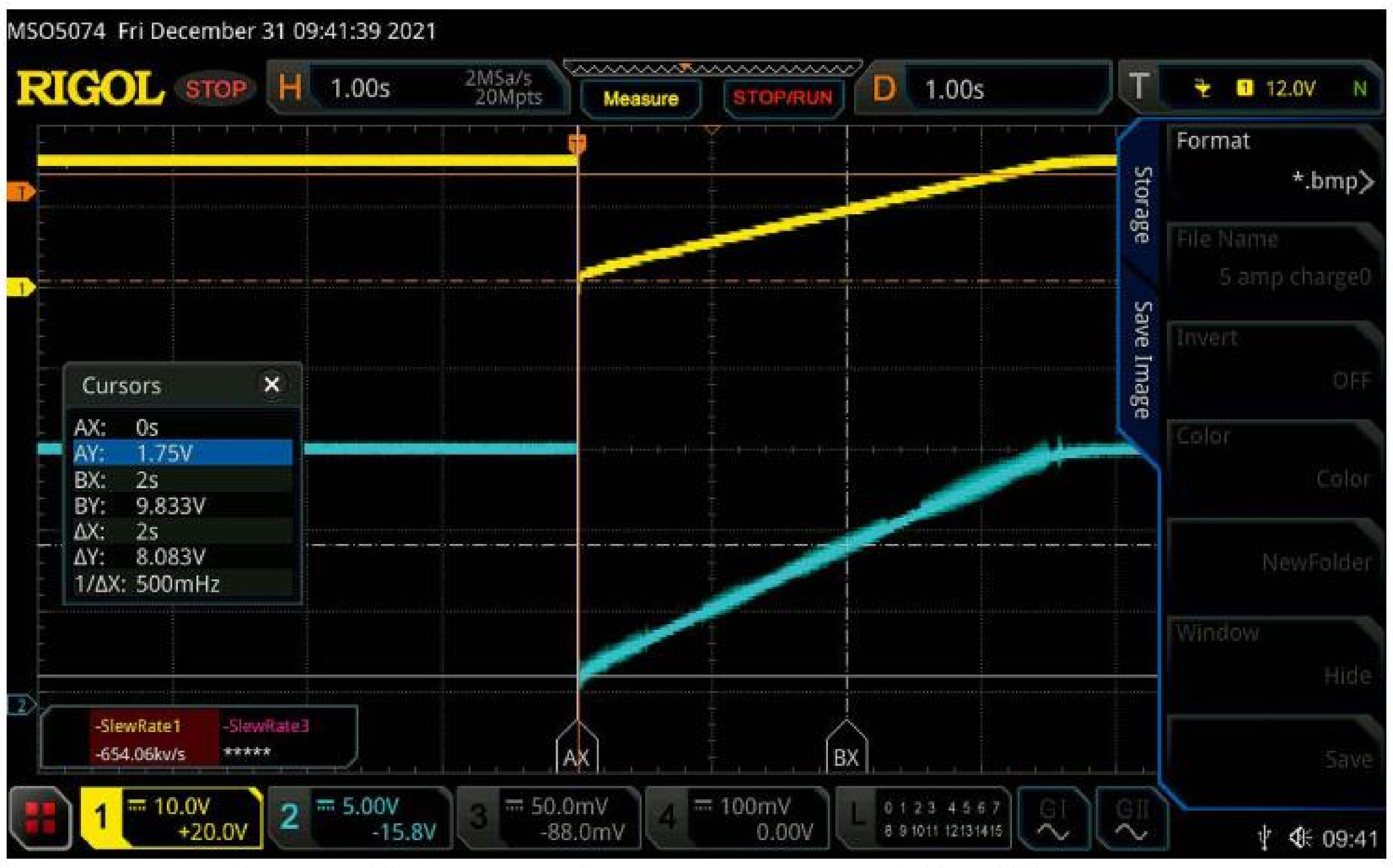
Resistors *(all SMD 1% M2012/0805 size unless stated)*
1 10kΩ
1 100Ω
2 10Ω
1 1.5kΩ 1W 5% axial (through-hole)

C = 2A ÷ (10.5V ÷ 0.616s) = 0.117F, which is pretty much spot on for three 39,000µF capacitors in parallel.

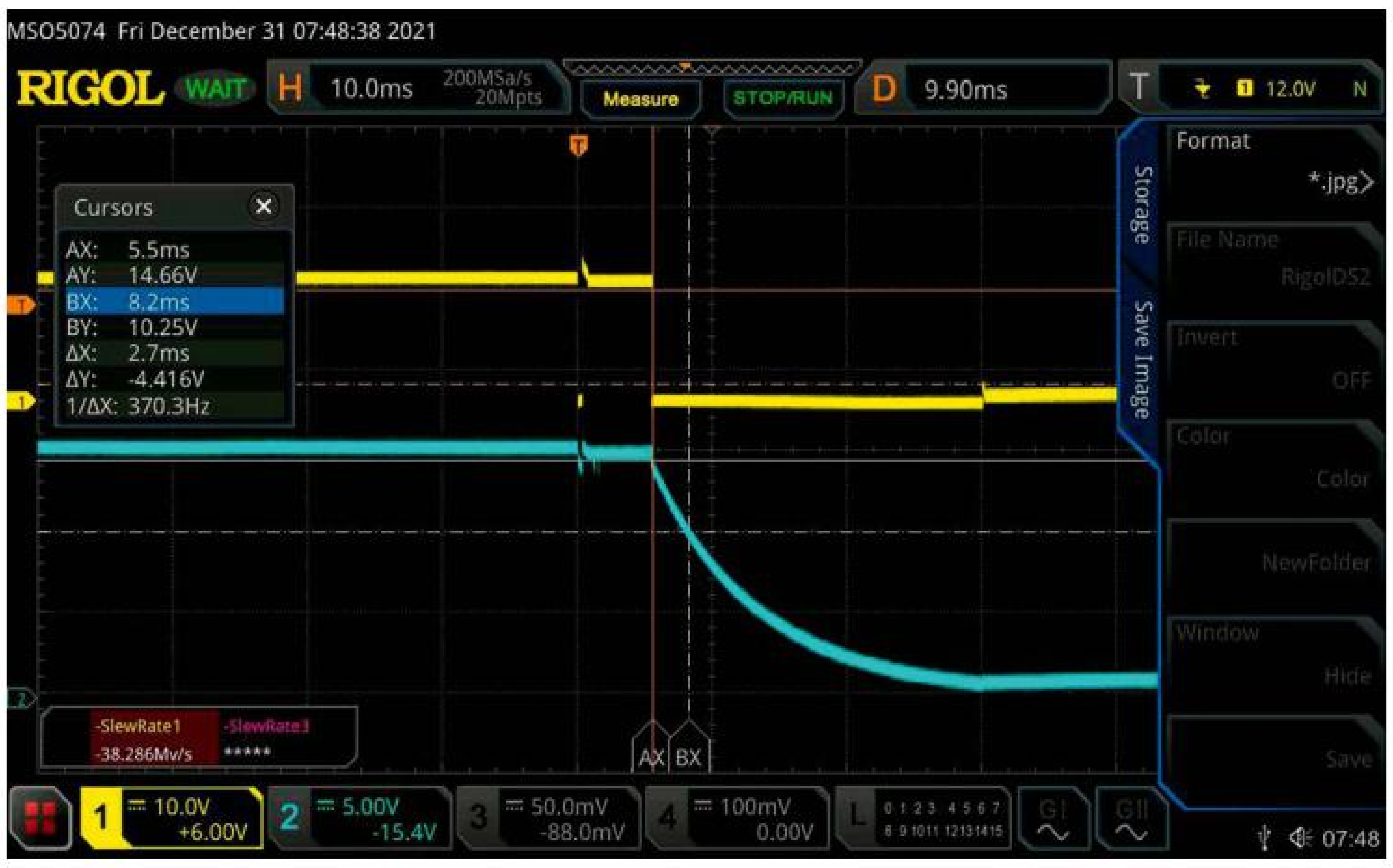
Scope 2 shows a similar curve for all ten ESMs in parallel. The voltage increases by 8.03V in two seconds at 4.8A, which tells us the bank in total is just under 1.2F.


MSO5074 Fri December 31 10:42:50 2021
RIGOL STOP
H 200ms
10MSa/s 20Mpts
Measure
STOP/RUN
D 238.98ms
T 12.0V
Format *.bmp
File Name 25 v pulse ...
Cursors
AX: 24ms
AY: 15.33V
BX: 640ms
BY: 4.833V
ΔX: 616ms
ΔY: -10.5V
1/ΔX: 1.623Hz
AX
BX
1 20.0V +40.0V
2 5.00V -17.2V
3 50.0mV -88.0mV
4 100mV 0.00V
10:42

Scope 1: the recharge voltage curve for a single Energy Storage module at 2A. The voltage increases by 10.5V in 616ms. Note also the discharge curve visible here, which we calculate as being 130A.


MSO5074 Fri December 31 09:41:39 2021
RIGOL STOP
H 1.00s
2MSa/s 20Mpts
Measure
STOP/RUN
D 1.00s
T 12.0V
Format *.bmp
File Name 5 amp charge0
Cursors
AX: 0s
AY: 1.75V
BX: 2s
BY: 9.833V
ΔX: 2s
ΔY: 8.083V
1/ΔX: 500mHz
-SlewRate1 -654.06kv/s
-SlewRate3 *****
AX
BX
1 10.0V +20.0V
2 5.00V -15.8V
3 50.0mV -88.0mV
4 100mV 0.00V
09:41

Scope 2: the recharge voltage curve with all ten ESMs in parallel. This time the charge rate is 5A, and using the formula given in the text, we calculate the total capacitance as a hair under 1.2F.


MSO5074 Fri December 31 07:48:38 2021
RIGOL WAIT
H 10.0ms
200MSa/s 20Mpts
Measure
STOP/RUN
D 9.90ms
T 12.0V
Format *.jpg
File Name RigolDS2
Cursors
AX: 5.5ms
AY: 14.66V
BX: 8.2ms
BY: 10.25V
ΔX: 2.7ms
ΔY: -4.416V
1/ΔX: 370.3Hz
-SlewRate1 -38.286Mv/s
-SlewRate3 *****
AX BX
1 10.0V +6.00V
2 5.00V -15.4V
3 50.0mV -88.0mV
4 100mV 0.00V
07:48

Scope 3: 200A pulse into a load. The yellow trace is the voltage on the negative output. The blue trace is for the capacitor voltage, which shows a dip for the initial pulse then exponential decay.

The welding cables and copper-tipped probes.

Turning now to what happens when the *CD Welder* is used, Scope 3 shows the *CD Welder* set to 15V welding tabs in a typical application. More voltage than this starts to blow holes in the tabs. This scope grab shows the 1.17F capacitor bank voltage dropping by 4.416V in

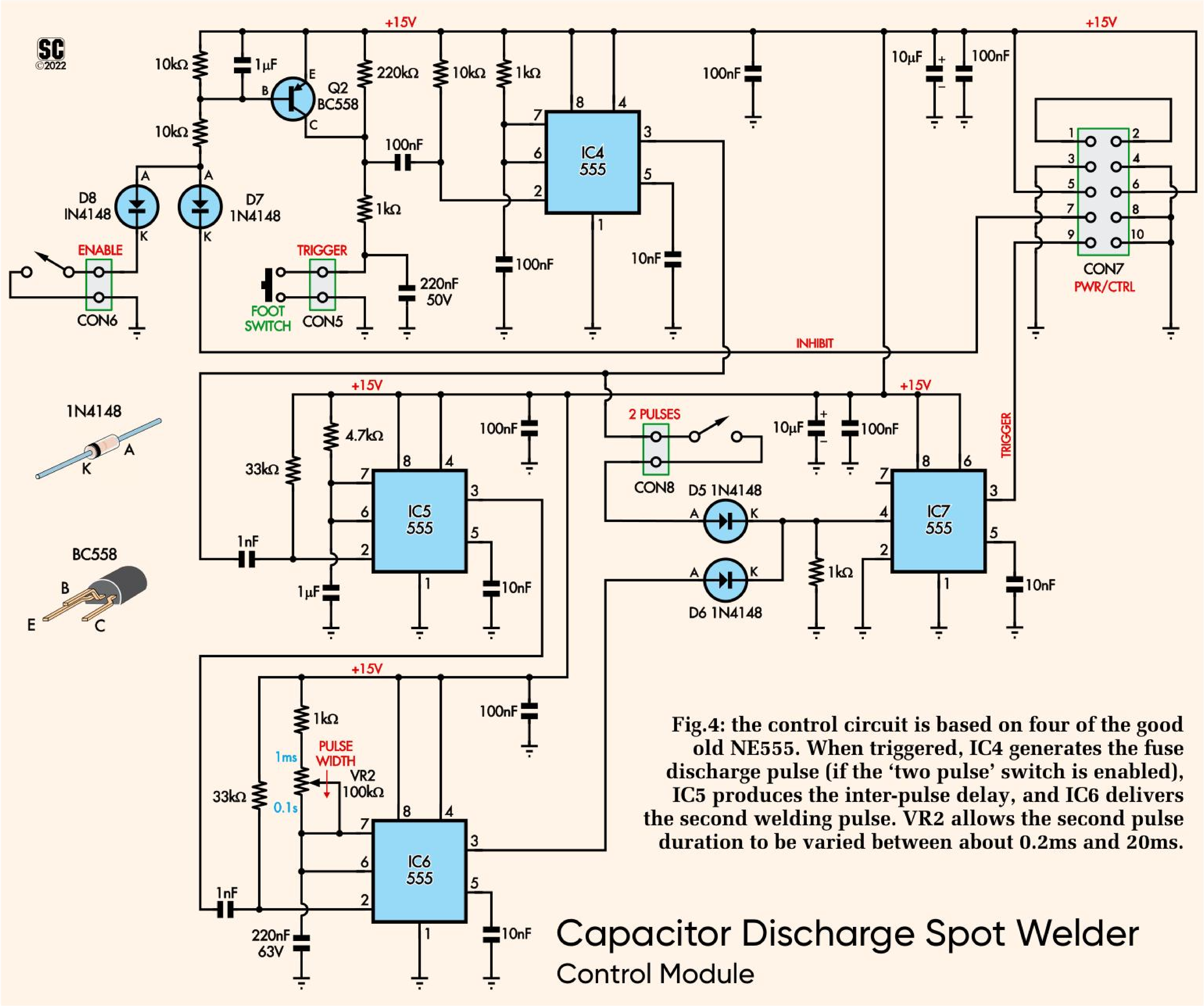

SC ©2022
+15V
10kΩ
1µF
E
B
Q2
BC558
C
220kΩ
10kΩ
1kΩ
7
8
4
IC4
555
3
6
2
5
1
100nF
10kΩ
A
D8
IN4148
K
D7
1N4148
1kΩ
100nF
10nF
ENABLE
CON6
TRIGGER
FOOT SWITCH
CON5
220nF 50V
10µF
100nF
CON7
PWR/CTRL
1 2 3 4 5 6 7 8 9 10
INHIBIT
TRIGGER
1N4148
BC558
B
E
C
4.7kΩ
33kΩ
1nF
1µF
IC5
555
10nF
2 PULSES
CON8
D5 1N4148
D6 1N4148
1kΩ
IC7
555
1kΩ
PULSE WIDTH
1ms
0.1s
VR2
100kΩ
33kΩ
1nF
220nF 63V
IC6
555
10nF
Capacitor Discharge Spot Welder
Control Module

Fig.4: the control circuit is based on four of the good old NE555. When triggered, IC4 generates the fuse discharge pulse (if the 'two pulse' switch is enabled), IC5 produces the inter-pulse delay, and IC6 delivers the second welding pulse. VR2 allows the second pulse duration to be varied between about 0.2ms and 20ms.

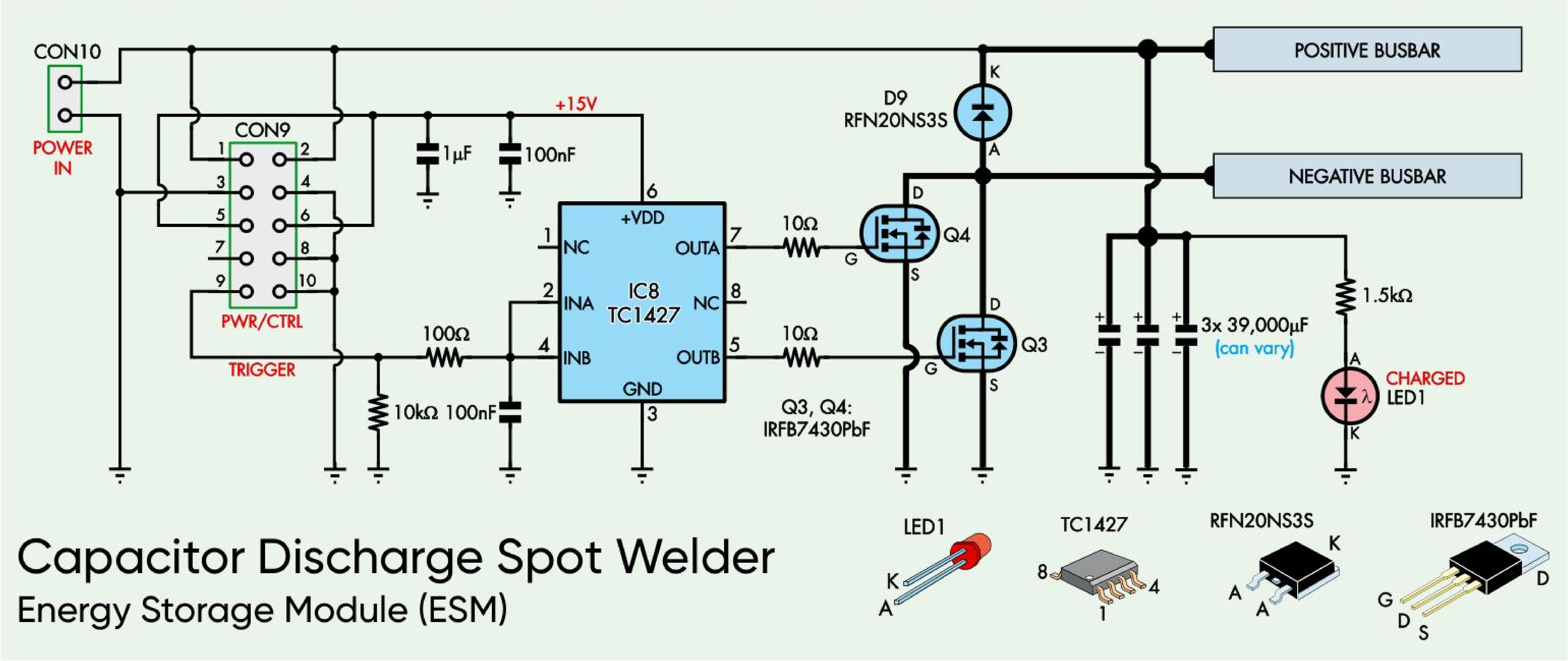

CON10
POWER IN
CON9
1 2 3 4 5 6 7 8 9 10
PWR/CTRL
TRIGGER
+15V
1µF
100nF
6
+VDD
1
NC
OUTA
7
2
INA
IC8
TC1427
NC
8
4
INB
OUTB
5
GND
3
100Ω
10kΩ
100nF
10Ω
10Ω
G
D
S
Q4
Q3
Q3, Q4: IRFB7430PbF
K
D9
RFN20NS3S
A
POSITIVE BUSBAR
NEGATIVE BUSBAR
3x 39,000µF
(can vary)
1.5kΩ
A
CHARGED LED1
K
LED1
TC1427
RFN20NS3S
IRFB7430PbF
K
A
8
4
1
G
D
S
Capacitor Discharge Spot Welder
Energy Storage Module (ESM)

Fig.5: the capacitors that store all the energy for welding are mounted on these ESMs, two or three per board. Each ESM also has two MOSFETs to dump their energy into the welding leads, a dual MOSFET driver to ensure they switch on and off cleanly, and a back-EMF clamping diode to catch any reverse spikes due to lead and other stray inductances.

2.7ms, which we calculate is a discharge of just under 2000A.

Next month

Next month we'll have the assembly details of the three modules, then the whole unit, plus testing and use instructions. In the meantime, you can peruse the parts list and start gathering the components you will need to build it.

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Mini PIC Training Course – Part 2

by Peter Brunning

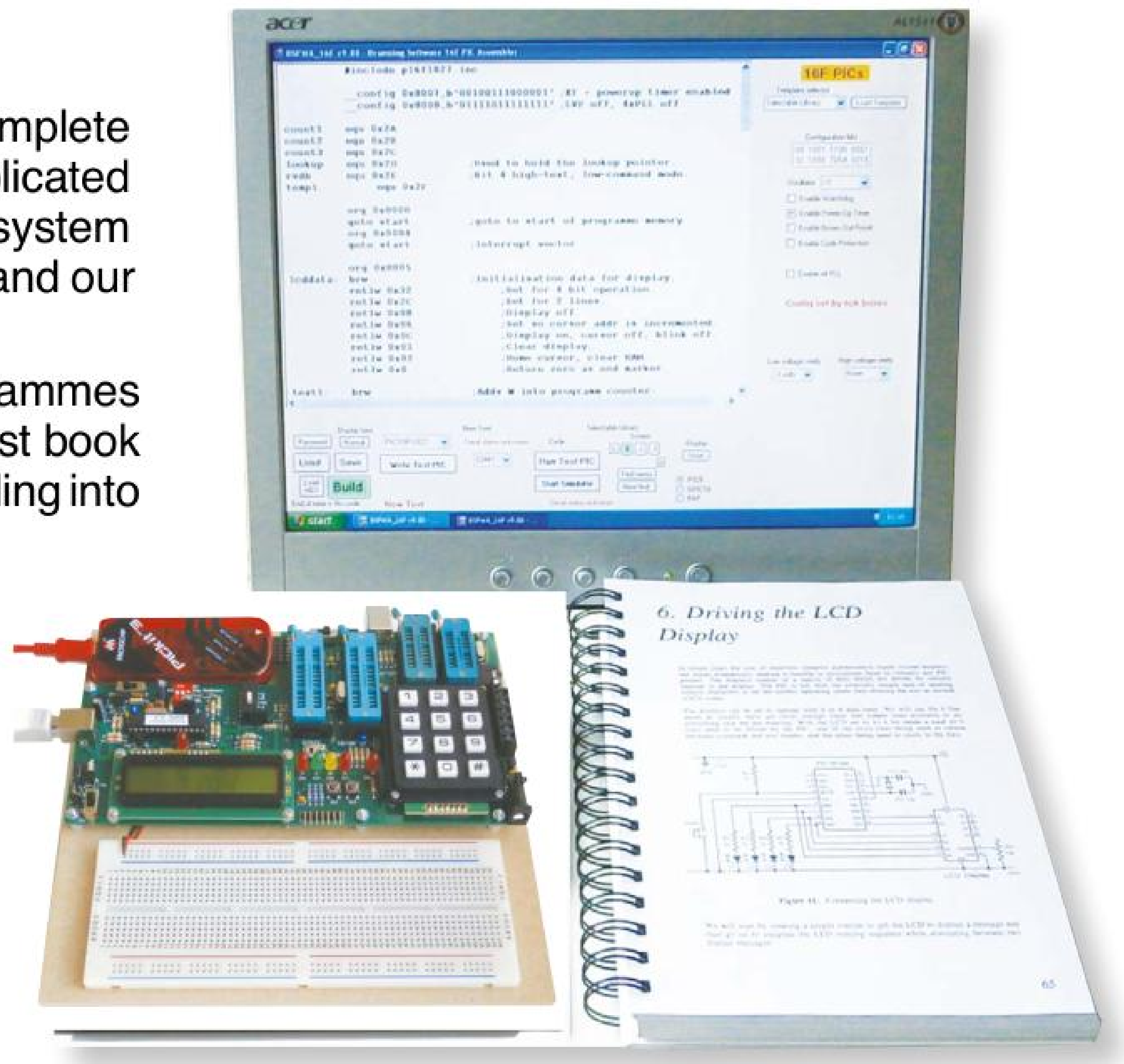
BSPWA
Copyright Brunning Software
GPICZv8

The second part of our Mini Training Course has two interesting objectives. The first is to create PIC code to measure temperature using three different sensors. The second is to measure the power from a solar panel. Both of these require knowledge of driving a display and using the PIC's Analogue-to-Digital Converter (ADC), so that is where we start.

Most of the code comes from the library, which is built into the BSPWA assembler, then we type in the instructions to link the required library routines. All the code is written to run in a PIC18F24K22 fitted in a GPICZv8 general-purpose training circuit. The GPICZv8 is shown on the left with LCD and keypad. The CD and 100-watt solar panel load are on the right.

The 144-page manual assumes a Brunning Software programmer is being used (P205, P931, P942 or P955). The price of £89 includes all the items in the picture, plus an LM35 and thermistor temperature sensor, a BMP280 temperature and air pressure sensor, and a P205. Price is £70 without P205. See our website for full details: **www.brunningsoftware.com**

The Brunning Software P955H PIC Training Course



When you are first learning about PICs, whether you are a complete beginner or an experienced programmer, you need an uncomplicated system which allows you to learn without getting bogged down in system procedure. That is why we created the P955H PIC training circuit and our own PIC assembler.

The first book teaches absolute beginners to write PIC programmes using assembler, which is the natural language of the PIC. The first book starts by assuming you know nothing about PICs, but instead of wading into the theory we jump straight in with four easy experiments. Then, having gained some experience, we study the basic principles of PIC programming, learn about the 8-bit timer, how to drive the alphanumeric liquid crystal display, create a real-time clock, and experiment with the watchdog timer, sleep mode, beeps and music. Then there are two projects to work through. In the space of 24 experiments, two project and 56 exercises we work through from absolute beginner to experienced engineer level using the latest 8-bit PICs (16F and 18F).

The second book introduces the C programming language for 8-bit PICs in very simple terms. The third book, *Experimenting with Serial Communications*, teaches Visual C# programming for the PC so that we can create PC programmes to control PIC circuits.

In the fourth book, we learn to programme 32-bit MX PICs using fundamental C instructions. Flash the LEDs, study the 16-bit and 32-bit timers, write text to the LCD, and enter numbers using the keypad. This is all quite straightforward as most of the code is the same as already used with the 8-bit PICs. Then life gets more complex as we delve into serial communications with the final task being to create an audio oscilloscope with advanced triggering and adjustable scan rate.

The complete P955H training course is £279, which includes the P955H training circuit, four books (240 × 170mm, 1200 pages total), six PIC microcontrollers, PIC assembler and programme text on CD, two USB-to-PC leads, a pack of components, and carriage to a UK address. (To programme 32-bit PICs you will need to plug in a PICkit 3 or 4. You can buy PICkit 4 from Microchip Direct for around £64).

Prices start from £189 for the P955H training circuit with Books 1 and 2 (240 × 170mm, 624 pages total), two PIC microcontrollers, PIC assembler and programme text on CD, USB-to-PC lead, and carriage to UK address. (PICkit 3 or 4 not needed for this option.) You can buy Books 3 and 4, USB PIC, 32-bit PIC and the components kit as required later. See the Brunning website for details: **www.brunningsoftware.com**

Mail order address:

Brunning Software

138 The Street, Little Clacton, Clacton-on-sea,
Essex, CO16 9LS. Tel 01255 862308

PICOMITE DEMO
24-11-2021 08:59:18
BACK PACK
GREEN
BLUE
10

Raspberry Pi Pico BackPack

By Tim Blythman

The Pico microcontroller board is a versatile and powerful ARM-based microcontroller on a small board for less than £5. There's quite a lot you can do with it on its own, but it's even better when connected to an LCD touchscreen.

The innovative Raspberry Pi Foundation's Pico microcontroller board is based on their own RP2040 microcontroller and is quite different from their popular line of Raspberry Pi single-board computers (SBCs). However, it shares a resemblance in its low price and ease of use.

It can be programmed using a C language compiler and SDK (software development kit) or via the Arduino IDE (integrated development environment), with the option of using the Mbed OS for ARM microcontrollers.

It's also possible to program the Pico using MicroPython, a variant of the Python programming language optimised for use on embedded devices.

In the July 2022 issue of *PE* we explained how to install MMBasic on a Raspberry Pi Pico, and then in the August, September and October 2022 issues we looked at using ready-made displays and boards to add display technology.

The Micromite pairs well with an LCD touchscreen, so we decided to create a bespoke matching *BackPack* for the Pi Pico as well. The *BackPack* not only allows the Pico to interface to an LCD touchscreen, but also includes other useful hardware.

While several other companies have designed boards around the RP2040 chip (including Arduino's Nano Connect, with a Wi-Fi module), our *BackPack* is designed to work with the original Pico board. We decided to concentrate on the Pico because it is low in cost, compact and versatile.

Raspberry Pi Pico

Here's a quick recap of the Pico. It's based around the Raspberry Pi Foundation's RP2040 microcontroller and has 264kB of internal RAM. Program storage is on a separate 2MB Flash chip.

The processor is a dual-core ARM operating up to a nominal 133MHz but it can usually be overclocked above 200MHz. The processor has 30 input/output pins, although not all are broken out. For example, some are used for Flash memory access.

It supports USB host and device operation. A ROM-based bootloader provides a convenient USB drive interface for uploading firmware images. Programming the Pico is as simple as copying a file.

It has the usual peripherals, like UART, SPI, I^{2}C and PWM. There are also two PIO peripheral modules. These are programmable I/O state machines that you can use to create more peripheral functions, or just more of those we've just mentioned.

The Pico BackPack

We've created something similar to the *Micromite BackPack V3* (August 2020), adding some extra features in the space that's available. Like the *BackPack V3*, it is designed to work with both the 2.8-inch and 3.5-inch LCD touchscreens.

We prefer a 3.5-inch display as it has a higher resolution and more area at a similar cost so we'll also show you how the Pico and *BackPack* can be programmed to use this display. Using the 2.8-inch screen is possible (and is very easy to do in PicoMite BASIC), but we will leave that as an exercise for the reader.

We'll present comprehensive example code for the PicoMite BASIC language, the C SDK, Arduino IDE and MicroPython languages. However, not all features are available in all languages.

Circuit

Fig.1 is the circuit diagram for the *Pico BackPack*. MOD1 is the Pico itself and a 14-pin header is provided to connect the LCD touchscreen (CON4). Since both the LCD and touch controllers on the panel use the SPI serial interface, we have wired the header to SPI-capable pins on the Pico.

The Pico's I/O pins have two different numbering systems. All have a physical number, which depends on their location on the package. This is the logical numbering that you would use if you think of the Pico module like an extra-wide 40-pin IC. This numbering system includes pins other than just those which can be used as I/Os. For example, pins 3, 8, 13, 18, 23, 28, 33 and 38 are all connected to ground.

The RP2040 general-purpose I/O pins also have a consecutive numbering scheme from GP0 to GP29, although some are not connected to pins 1-40. Most programming languages use the GP numbering system (sometimes dropping the GP prefix), although PicoMite BASIC allows you to use either.

For the system SPI bus used to interface with the LCD panel, GP18 (pin 24) is the SPI clock (SCK), GP19 (pin 25) is MOSI and GP16 (pin 21) is MISO. Note that the MISO signal travels via JP2 to the LCD's pin 9. This jumper can usually be left off as data does not need to be sent from the LCD controller back to the Pico.

Other control pins include the LCD controller's $\overline{\text{CS}}$ (chip select), RST (reset) and D/C (data/command) lines, which map to GP12 (pin 16), GP13 (pin 17) and GP14 (pin 19) respectively.

The touch controller uses the same main SPI lines as the LCD with its own CS and IRQ lines: GP15 (pin 20) and GP17 (pin 22), respectively.

GP20 (pin 26) is used to control the LCD panel's LED backlight if JP1 is in place. If JP1 is absent, the 10kΩ resistor pulls N-channel MOSFET Q2's gate high, which in turn pulls P-channel MOSFET Q1's gate low, continuously supplying 5V into the LED pin and keeping the backlight on full permanently. The same thing happens if GP20 is actively pulled high; the LED pin receives 5V.

If GP20 is driven low and JP1 is in place, the LCD backlight is switched off, while a PWM signal from this pin creates a range of backlight brightness levels.

Pushbutton switch S1 is connected between the Pico's 3V3_EN pin and ground. The 3V3_EN pin connects to the enable pin of the Pico's onboard 3.3V regulator and is normally pulled high by a 100kΩ resistor on the Pico. When it is pulled low, the 3.3V supply to the microcontroller is shut down. Thus a brief press of S1 will reset the microcontroller.

The RT6150 regulator fitted to the Pico is a buck-boost type and can operate from an input voltage between 1.8V and 5.5V. But be aware that the

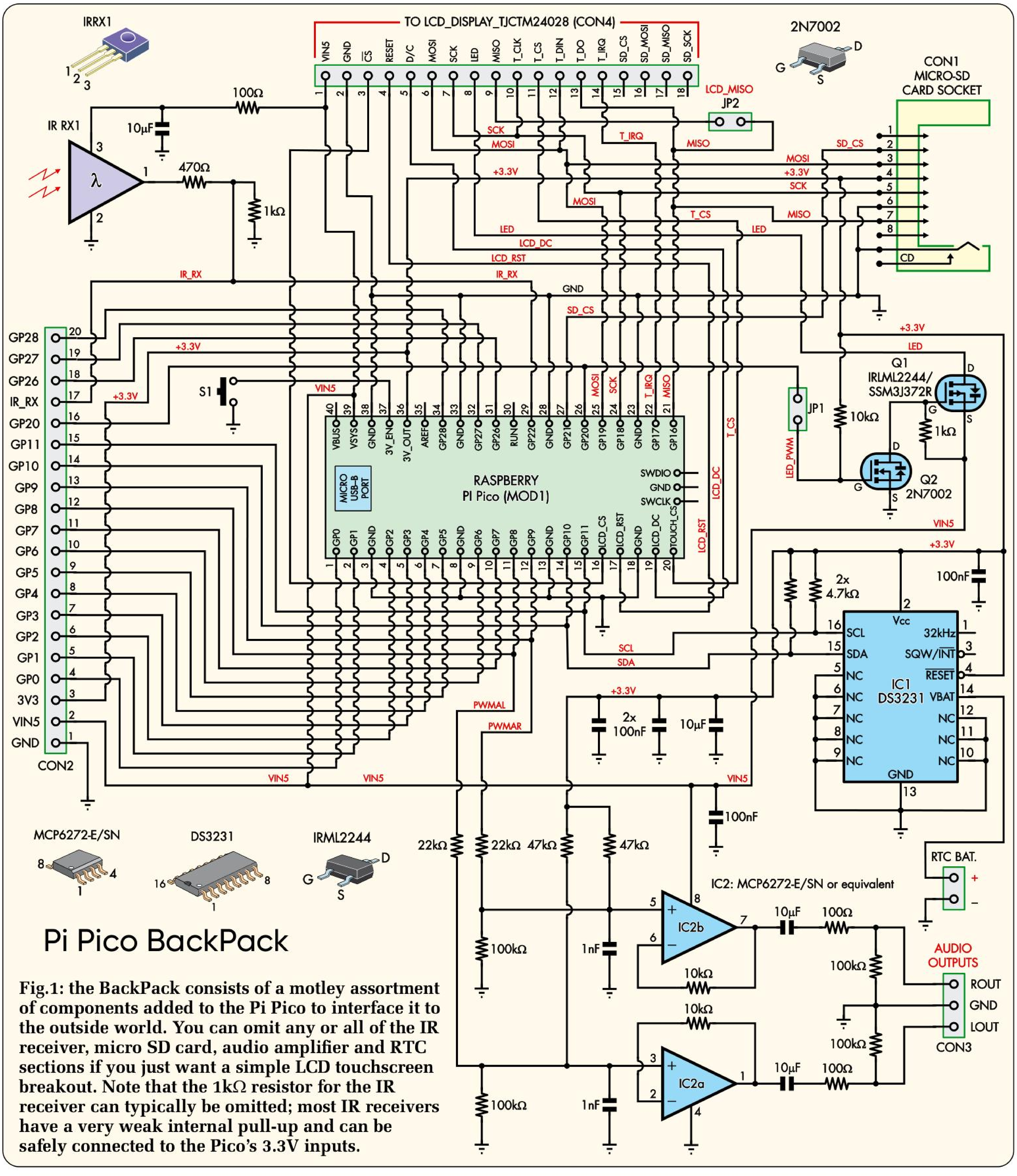
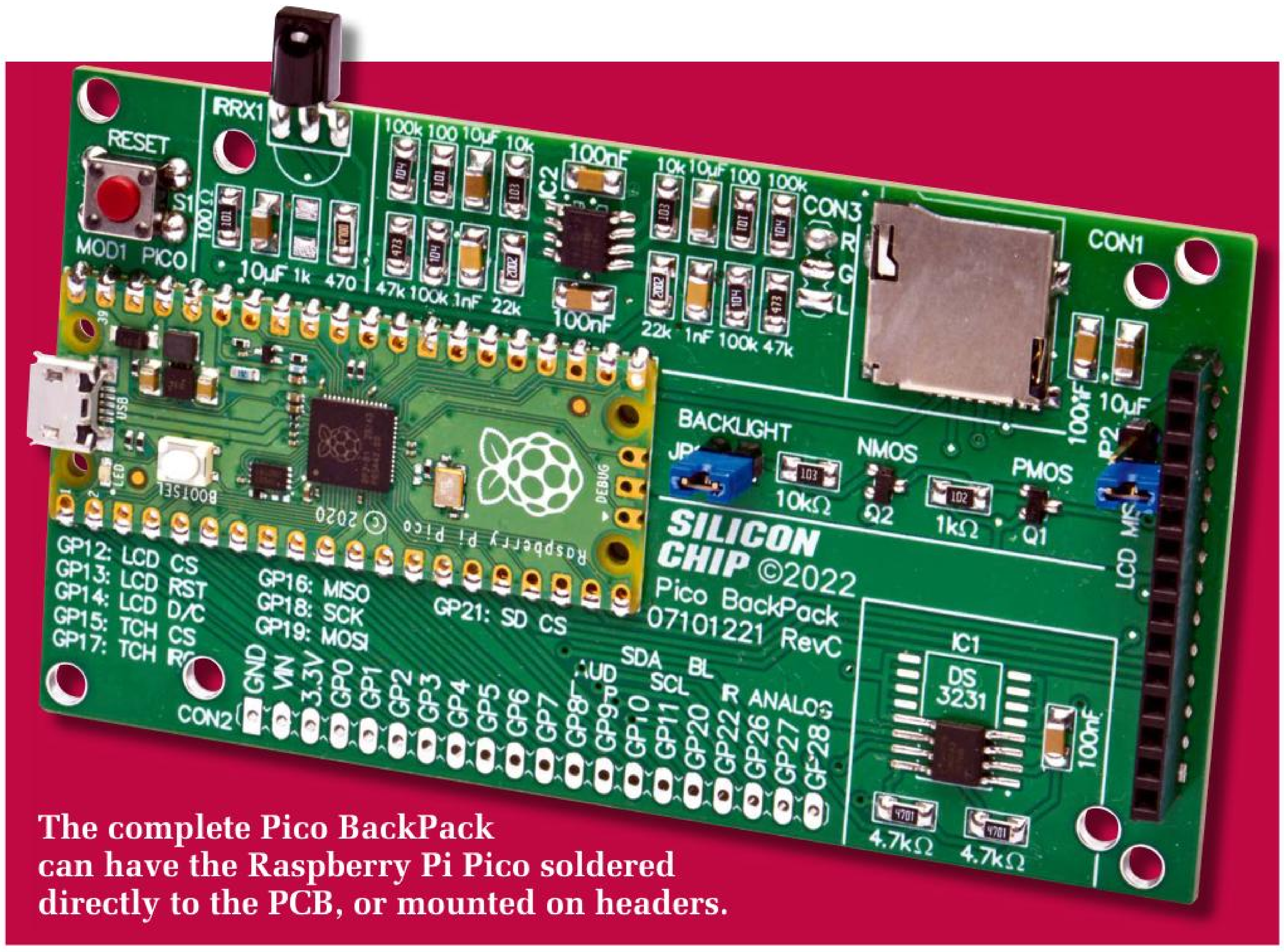

Pi Pico BackPack
IRRX1
IR RX1
TO LCD_DISPLAY_TJCTM24028 (CON4)
VIN5
GND
CS
RESET
D/C
MOSI
SCK
LED
MISO
T_CLK
T_CS
T_DIN
T_DO
T_IRQ
SD_CS
SD_MOSI
SD_MISO
SD_SCK
2N7002
CON1 MICRO-SD CARD SOCKET
CD
LCD_MISO
JP2
100Ω
10µF
470Ω
1kΩ
IR_RX
LCD_DC
LCD_RST
+3.3V
S1
JP1
LED_PWM
10kΩ
Q1 IRLML2244/ SSM3J372R
Q2 2N7002
RASPBERRY PI Pico (MOD1)
MICRO USB-B PORT
SWDIO
SWCLK
VBUS
VSYS
3V_EN
3V_OUT
AREF
RUN
LCD_CS
TOUCH_CS
GP28
GP27
GP26
GP20
GP11
GP10
GP9
GP8
GP7
GP6
GP5
GP4
GP3
GP2
GP1
GP0
3V3
CON2
SCL
SDA
2x 4.7kΩ
100nF
IC1 DS3231
Vcc
32kHz
SQW/INT
RESET
VBAT
NC
PWMAL
PWMAR
2x 100nF
22kΩ
47kΩ
100kΩ
1nF
IC2: MCP6272-E/SN or equivalent
IC2b
IC2a
RTC BAT.
AUDIO OUTPUTS
ROUT
LOUT
CON3
MCP6272-E/SN
DS3231
IRML2244

Fig.1: the BackPack consists of a motley assortment of components added to the Pi Pico to interface it to the outside world. You can omit any or all of the IR receiver, micro SD card, audio amplifier and RTC sections if you just want a simple LCD touchscreen breakout. Note that the 1kΩ resistor for the IR receiver can typically be omitted; most IR receivers have a very weak internal pull-up and can be safely connected to the Pico's 3.3V inputs.



The complete Pico BackPack can have the Raspberry Pi Pico soldered directly to the PCB, or mounted on headers.

infrared receiver and LCD controller might not work over that entire range. We recommend supplying at least 3.3V to the *BackPack* if you plan to use those features.

Optional infrared receiver IRRX1 is fed from the board's USB supply (nominally 5V) via a 100Ω resistor and bypassed by a 10μF capacitor. The 5V output of IRRX1 is divided by a 470Ω/1kΩ divider to 3.3V, and this signal connects to GP22 (pin 29) of the Pico.

Some IR receivers have an internal pull-down (open collector/drain) transistor complemented by a weak internal pull-up. In this case, the 1kΩ resistor can be left out as the weak pull-up, and the 470Ω series resistor will limit current from the 5V rail into the 3.3V microcontroller.

CON1 is a micro SD card socket powered from the 3.3V rail and with its SPI pins (SCK, MOSI and MISO) connected to the same SPI pins as the LCD touchscreen. Its CS (chip select) pin connects to GP21 (pin 27) on the Pico. The supply to the micro SD card is bypassed by 100nF and 10μF capacitors for reliable operation.

IC1 is an optional DS3231 or DS3231M real-time clock and calendar IC with its own 100nF bypass capacitor to the 3.3V supply rail. It communicates with the micro via an I^{2}C serial bus, and the 4.7kΩ pull-up resistors to the 3.3V rail required for I^{2}C communication are also provided. The I^{2}C SDA and SCL (data and clock) signals connect to the Pico's GP10 (pin 14) and GP11 (pin 15).

A cell holder (BAT1) is also provided to allow the RTCC to keep time when the main power supply is off.

20-pin header CON2 breaks out some of the Pico's spare pins. These include 17 GPIO pins that are otherwise unused or can be shared with devices on the *BackPack*.

The GND, 3.3V and VSYS (VIN) pins on the Pico also connect to this header. The GND and VSYS pins can be used to power the *BackPack* or feed power from the *BackPack* to other parts, while the 3.3V pins should be considered an output only.

The circuitry around IC2 is intended to convert a pair of PWM signals from GP8 (pin 11) and GP9 (pin 12) into stereo line-level signals at CON3.

While we could have fitted an I^{2}S DAC IC instead for higher audio quality, the PicoMite can play audio via PWM natively, and it's pretty easy to implement this in other languages (as we have done in some of our sample code). The PWM implementation also costs much less.

Each PWM signal is treated the same. A low-pass and biasing network formed from the 22kΩ, 47kΩ and 100kΩ resistors shifts the 0V to 3.3V signal to around 0.9-2.9V. The 1nF capacitor also removes high-frequency PWM artifacts, with a –3dB point around 13kHz.

IC2 is a dual op amp fed from the 5V rail with both of its channels configured for unity gain, so it produces a 2V peak-to-peak signal (around 700mV RMS) with a DC offset of 1.9V. The 10μF capacitor and 100kΩ bias resistor remove the DC offset, with the 100Ω resistor protecting the op amp from short circuits on the output.

The audio output is available at CON3, with the centre pin being ground. The signal here is suitable for driving headphones, a small speaker or an amplifier.

PCB features

The *Pico BackPack* PCB is sized to match the 3.5-inch LCD touchscreen. Header CON4 at one end connects to the LCD touchscreen while CON2, along one edge, provides connections to a breadboard or other hardware (eg, a 'daughterboard').

The Pico mounts opposite the LCD header, allowing its micro-USB socket to be accessible from the edge of the PCB (avoiding the need for us to fit a separate USB socket). To match the Pico itself, we've provided pads to mount it on headers or to solder it directly to the PCB, as though it were a surface-mounting component.

The latter is preferred for permanent installations, as using headers would require extended headers on the LCD panel to provide clearance below. A third option is to fit the Pico with female headers above and male headers below the *Pico BackPack*, bypassing the clearance issue.

Our parts list assumes the direct mounting method. If you wish to use headers, you will need two extra pairs of 20-pin, 2.54mm pitch male and female header strips.

You can use the Pico's onboard bootloader pushbutton (adjacent to its micro-USB socket) along with S1 to enter bootloader mode. The sequence is to hold down the bootloader button, press and release S1, then release the bootloader button. S1 removes the need to plug and unplug the Pico for programming, which would otherwise cause wear to its USB socket (or your PC's).

With the LCD header on the right, the micro SD socket and IR receiver sit at the top for ease of access. The body of the IR receiver can be bent backwards to allow the lens to face the same direction as the screen.

Optional sections

The photos and overlay diagram show that the PCB is divided by lines into sections corresponding to each hardware feature. This allows you to fit or not fit the various features as needed.

The PCB silkscreen also has the pin information printed along its bottom half. The default SPI pins for the LCD, touch and micro SD card are described on the left-hand side, while each pin of CON2 is also marked with its corresponding Pico pin connection.

With all the features fitted, you have eleven spare I/O pins: GP0 to GP7 and GP26 to GP28, although the I^{2}C pins GP10 and GP11 can also be shared with other I^{2}C devices. GP26 to GP28 are the only externally-available pins that can be used as analogue inputs.

Deleting the audio section frees up GP8 and GP9, while not using the LCD backlight control pin frees up GP20. With only the LCD touchscreen fitted, you can have up to 17 free I/O pins.

With this in mind, you can plan what onboard and offboard circuitry will be needed for your *Pico BackPack*, allowing you to decide what parts you do and don't need to fit.

Our demo code is focused on the *BackPack's* features and does not require any external parts beyond the LCD touchscreen and a speaker connected to CON3.

Construction

We'll describe the construction as though all parts are fitted. You can skip any that you don't want to install.

As most of the onboard parts are SMDs to save space, you will need flux paste and a magnifier as well as a soldering iron. We also recommend that you have some solder wicking braid and a suitable cleaning solvent for your flux.

Since flux can generate harmful smoke, fume extraction is a good idea. If you don't have any fume extraction, work outside or near an open window. This may also help with providing good illumination.

The *Pico BackPack* is built on a 99 x 55mm double-sided PCB, coded 07101221 and available from the *PE PCB Service*. Refer to the overlay diagram, Fig.2, during construction.

Start by fitting the micro SD card socket, CON1. Apply flux to the pins and rest the socket in place. It has locating posts, so it is easy to align. Add some more flux to the top of the pins too.

Clean the tip of the iron, add a small amount of fresh solder and apply it to the socket's pins, taking care not to contact the metal shell of the socket.

If you are happy with the pin soldering, solder the mechanical tabs too. If there are any bridges, use solder braid to remove them by adding some more flux, cleaning the iron's tip and pressing the braid against the bridge with the iron. Carefully slide both away together once the wick has soaked up the excess solder.

Next, fit the two ICs. There are variants of IC1 in both 16-pin and 8-pin packages. The SOIC-16 part uses all the pads, while the narrower SOIC-8 part will use the lower eight extended pads. Regardless, IC1's pin 1 is at the lower right.

If you can't make out a pin 1 marking on IC1's case, look for a bevel along one edge. This will be the edge with pin 1.

IC2's pin 1 goes to the upper left. For the ICs, apply flux, rest the part in place, aiming to align it squarely and symmetrically. Add more flux to the tops of the pins and clean the iron tip. Add some solder and tack one pin in place. Confirm that the part is flat against the PCB and still positioned correctly; if not, reapply heat and nudge the part into alignment.

Solder the remaining pins and only then remove any bridges if necessary.

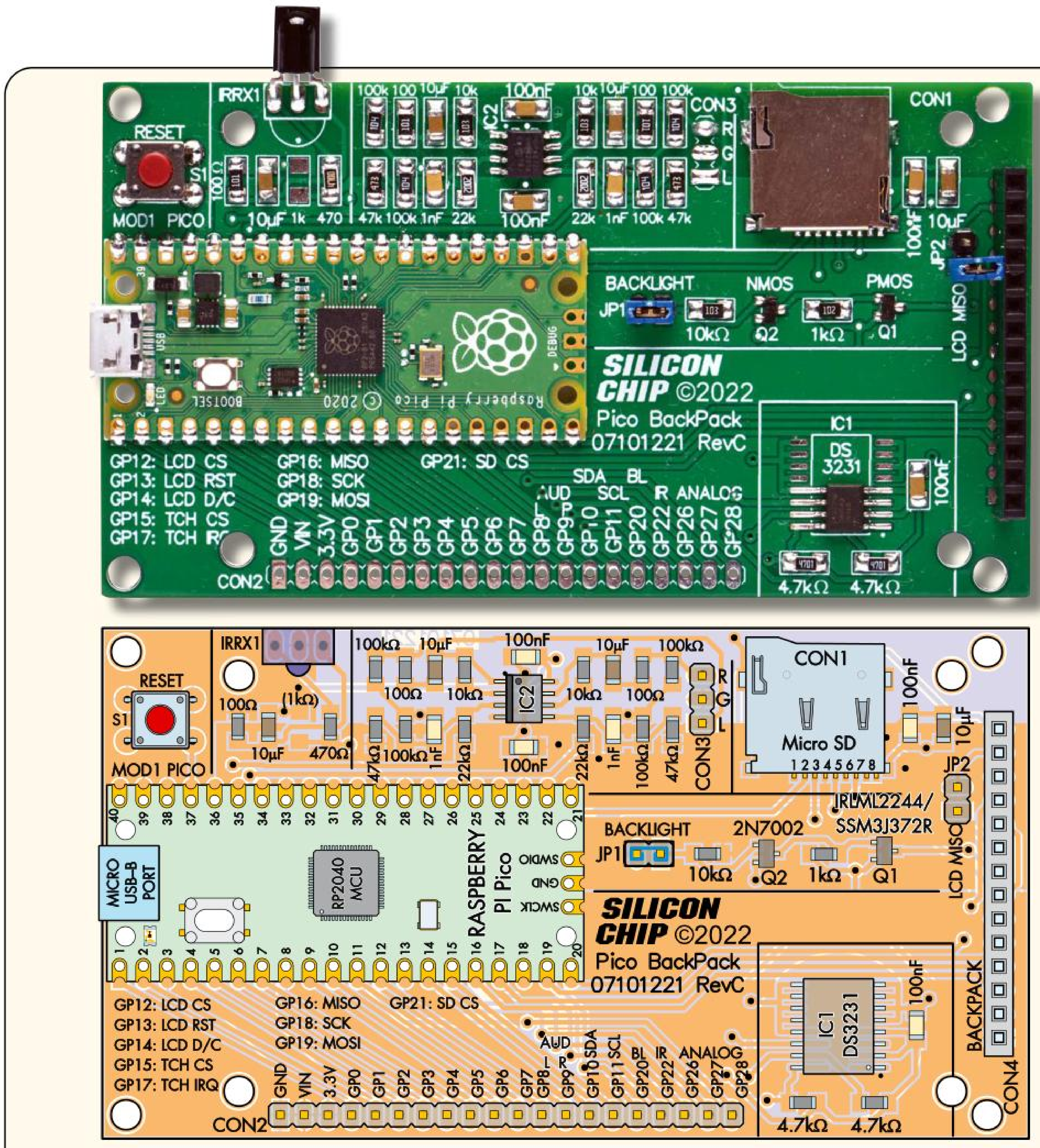


Fig.2: the lines on the PCB mark the regions and components that correspond to the optional features. From the left, the IR receiver, audio amplifier and micro SD card socket sit along the top of the PCB, providing external access. The RTCC is at the lower right. If fitting the RTC components, don't forget the battery holder on the rear of the PCB.

For transistors Q1 and Q2, use a similar process as the ICs. The SOT-23 parts are small but easy enough to solder – as long as you don't lose them!

Move onto the capacitors next. We recommend working with one value at a time, as they will probably be unmarked. The procedure for passives is much the same as ICs: tack one lead and confirm that the parts are flat, square and centred, then solder the other lead. Refresh the first joint with some flux and a touch of the iron if it doesn't look glossy.

Fit the four 10µF capacitors in the positions shown in Fig.2, then follow with the four 100nF parts and the two 1nF capacitors in the audio section.

Now move on to the resistors. Match up the part codes with those given in our parts list and the PCB silkscreen markings. You can use our *SMD Test Tweezers* (October 2022) to measure and place these parts.

With most of the SMDs fitted, it is a good time to clean the board of flux. While the Pico and cell holder are surface mounting, they will not need much flux, if any. Remember to allow any solvent to evaporate fully before continuing.

If you have 2mm machine screws, you can use these to align the Pico (MOD1) with the holes in the PCB. Remember that the USB socket hangs off the edge of the board. If you don't have screws, tack one or two of the module's pads in place instead.

The pads are large enough that you can apply solder directly after heating the pad with the iron. Work around the edge of the part, applying the iron and solder to the point where the Pico's outermost half-holes meet the PCB.

If you prefer to use detachable headers, use the innermost row of holes on the Pico and PCB. Once the Pico is soldered, you can remove any screws; the 40 solder joints should keep it secure.

Flip the PCB over to attach the cell holder BAT1. The opening should face the edge of the PCB. Rest the holder in place, tack one lead down, solder the other lead, then refresh the first.

Now snap S1 in place, ensuring it is flat against the PCB, then solder all its pins.

Consider how you plan to use the IR receiver and whether it needs to be bent up to receive a signal from the desired direction. If you are unsure, sit it up from the PCB slightly so that there is room to change this later. You could even mount it on the reverse of the PCB, as long as the pins go to the same pads.

The only parts left are the headers and jumpers. Depending on your plans,

Parts List – Pico BackPack

1 double-sided PCB coded 07101221, 99 x 55mm available from the *PE PCB Service*
1 Raspberry Pi Pico Module (MOD1) **[Altronics Z6421, Digi-Key, Mouser, Core Electronics]**
1 3.5-inch LCD touchscreen with an ILI9488 controller and SPI interface **[eg, https://bit.ly/pe-mar23-35lcd]**
1 14-pin, 2.54mm pitch socket header (for LCD panel)
1 20-pin, 2.54mm pitch pin header (CON2)
2 2-pin, 2.54mm pitch pin headers with jumper shunts (JP1, JP2)
1 6mm x 6mm tactile switch (S1)
8 M3 x 6mm panhead machine screws
4 M3 x 12mm tapped spacers

Semiconductors
1 IRLML2244TRPBF/SSM3J372R P-channel MOSFET, SOT-23 (Q1)
1 2N7002 N-channel MOSFET, SOT-23 (Q2)

Resistors *(all M3216/1206, 1%, ⅛W)*
1 10kΩ 1 1kΩ

Optional Components

SD card
1 SMD micro SD card socket (CON1) **[Altronics P5717]**
1 10µF 10V X7R SMD ceramic capacitor, M3216/1206 size
1 100nF 10V X7R SMD ceramic capacitor, M3216/1206 size

Real time clock/calendar
1 surface-mounting CR2032 cell holder (BAT1) **[BAT-HLD-001]**
1 DS3231 or DS3231M in SOIC-16 (wide) or SOIC-8 package (IC1)
1 100nF 10V X7R SMD ceramic capacitor, M3216/1206 size
2 4.7kΩ 1% ⅛W M3216/1206 size

IR receiver
1 3-pin infrared receiver (IRRX1)
1 10µF 10V X5R SMD ceramic capacitor, M3216/1206 size
1 1kΩ 1% ⅛W resistor M3216/1206 size
1 470Ω 1% ⅛W resistor M3216/1206 size
1 100Ω 1% ⅛W resistor M3216/1206 size

Stereo audio
1 MCP6272(T)-E/SN, MCP6002(T)-I/SN or -E/SN dual op amp, SOIC-8 (IC2)
1 3-pin, 2.54mm pitch pin header (CON3; see text for other options)
2 1nF 25V X7R SMD ceramic capacitors, M3216/1206 size
2 100nF 10V X7R SMD ceramic capacitors, M3216/1206 size
2 10uF 10V X5R SMD ceramic capacitors, M3216/1206 size
4 100kΩ 1% ⅛W resistor M3216/1206 size
2 47kΩ 1% ⅛W resistor M3216/1206 size
2 22kΩ 1% ⅛W resistor M3216/1206 size
2 10kΩ 1% ⅛W resistor M3216/1206 size
2 100Ω 1% ⅛W resistor M3216/1206 size

either of the jumper headers could be left off or replaced with wire loops as a permanent jumper.

To run our example code, fit both jumper headers, but place the shunt for JP1 (LCD Backlight) on and leave the shunt for JP2 (LCD MISO) off. You can pre-fit the shunt to the header to help you hold it in position while soldering the first pin.

Now add CON3 in the audio section. It's designed for jumper wires to take these signals where they are needed. You could solder wires directly to these pins if desired. Depending on your application, you might find that fitting right-angled headers will work better, and there is also the option of fitting the headers to the underside of the PCB if required, which is what we did for our prototypes.

To ensure that the headers between the LCD panel and main PCB are fitted squarely, you can assemble the stack using the machine screws and tapped spacers, as seen in our photos.

Note that the four-pin header on the LCD (for its onboard SD card socket) should not be populated, as this will foul the USB socket on the Pico. Fit the female header to the male header on the LCD panel and assemble the stack. Then solder the female header in place and separate the stack.

The last piece is the 20-pin I/O header, CON2. If you wish to use the *Pico BackPack* with a breadboard, fit this underneath the PCB. Alternatively, use right-angle headers to bring these connections out the side. Or you can even leave it off for now, as none of our examples need any external connections. You can always add it later.

Reattach the LCD panel to the *BackPack* and secure it by screwing the machine screws into the tapped spacers.

Testing

Before diving in, you might like to quickly test that everything is working as expected with your *BackPack*. For this, you can simply upload our compiled **BackPackTest.UF2** file.

Put the Pico into bootloader mode by holding the bootloader button (on the Pico) while resetting it (by pressing S1) or powering it up. Then copy the UF2 file onto the RPI-RP2 disk that appears. The demo should start as soon as the file finishes copying – see Screen 1.

This example uses PicoMite BASIC, so you can also use this file as a starting point for your own BASIC program; simply use Ctrl-C on a serial terminal to stop the running program.

The demonstration programs all provide buttons for interaction and let you use the touchscreen to draw on the LCD screen.

PicoMite BASIC demo

With PicoMite BASIC having native support for the ILI9488 driver on the 3.5in LCD touchscreen, only a few commands are needed to set everything up, if you prefer to do this manually. You'll need a serial terminal program such as TeraTerm or MMEdit (on Windows) or minicom (on Linux).

If you haven't already done so, load PicoMite BASIC onto the Pico by entering bootloader mode and copying the PicoMite UF2 file. Find the serial port of the Pico and open it with the terminal program. As it is a virtual serial port, no baud rate needs to be set.

The following options will configure the PicoMite to use the *BackPack* hardware, including the LCD, touchscreen, micro SD card socket, I^2C for the RTCC, audio and the GUI controls that are used in our demo:

```
OPTION SYSTEM SPI GP18,GP19,GP16
OPTION SDCARD GP21
OPTION LCDPANEL ILI9488, LANDSCAPE,GP14,GP13,GP12
OPTION TOUCH GP15,GP17
GUI CALIBRATE
OPTION SYSTEM I2C GP10, GP11
OPTION AUDIO GP8, GP9
OPTION GUI CONTROLS 20
```

Note that the PicoMite resets every time an option is set, dropping the serial connection; we like how TeraTerm reconnects automatically after a reset as this makes issuing a string of such commands easier.

After doing this, you can load our example code. To do this via the terminal, enter the `AUTOSAVE` command and paste the BASIC program into the terminal. The supplied file ends with an ASCII code 26 (0x1A) character, which BASIC interprets as a Ctrl-Z keypress signifying the end of the file. Then type `RUN` followed by Enter to start the demo.

After this, the Pico is in much the same state as if loaded with our example UF2 file, although possibly with more accurate touchscreen calibration.

We recommend having a read through the PicoMite manual to learn the minor differences from the Micromite. However, most of the differences that we came across are in the `OPTION`s described above.

MicroPython demo

MicroPython has some parallels with BASIC in that it features an interactive prompt, allowing commands and programs to be easily tested. MicroPython has been ported to several other 32-bit microcontrollers such as the ESP32. If you'd like to find out more, see: **https://micropython.org/**

It is open-source, and you can find the source code at: **https://github.com/micropython/micropython** but we've also included a copy of the version 1.17 UF2 file that we used to develop our examples.

Typically, you will need an IDE to manage the code files, although it is possible to get by with a serial terminal program. We used 'Thonny' as our Python IDE, as it appears in recent Raspberry Pi OS distributions and is also available on Windows.

You can load the **BackPack MicroPython Example.UF2** file directly via bootloader mode. This is the easiest method if you don't have a Python IDE installed. As with the PicoMite BASIC example, you can interrupt code loaded via the bootloader and interact with it through a serial terminal. Otherwise, follow the steps below to view and work with the source files separately.

We are using MicroPython for Pico version 1.17. To load our example manually, first load the MicroPython UF2 file onto the Pico, then use your IDE to copy the **ILI9488LIB.py** and **LSNBFONT.py** files to a 'lib' folder on the Pico's internal storage. The way this is done will vary depending on the IDE you're using.

These two modules constitute the driver and font that are used in our software, and keep the main program file legible and to a manageable size.

Now load the **main.py** file and run it. If all is well, you should see the screen initialise – see Screen 2.

Unlike PicoMite BASIC, we had to implement the display driver in Python. While this makes it noticeably slower than BASIC's integrated driver, it is certainly fast enough to be usable.

We haven't delved into creating libraries for the micro SD card, RTCC or IR receiver as there are numerous publicly available libraries for these features.

Do not insert a micro SD card unless you have already installed a library to initialise it correctly. Otherwise, it will interfere with the SPI bus operation of the LCD and touch controllers.

Arduino demo

We used a board variant based on the C SDK for our Arduino software, which simplified developing software for the C SDK by itself. This is the board variant we mentioned in the Pi Pico Review (**https://github.com/earlephilhower/arduino-pico**).

To add this variant to the Arduino IDE, add the text 'https://github.com/earlephilhower/arduino-pico/releases/download/global/package_rp2040_index.json' to the list of Board Manager URLs under Arduino Preferences.

Next, install the 'Raspberry Pi Pico/RP2040' option from the Boards Manager by selecting it and clicking 'Install' (as shown in Screen 3). Our example code just needs one example library; search for 'rtclib' in the Library Manager and install the version provided by Adafruit. It can also be downloaded and installed manually from **https://github.com/adafruit/RTClib**

The SD card library included with the Arduino IDE is used by our code. We've also written simple drivers for the LCD touchscreen (including backlight PWM) and audio output. The files for these are included in our sample code.

Unfortunately, it appears there are no readily available IR receiver libraries for the Pico under Arduino yet. We previously used the Arduino IRremote library (**https://github.com/Arduino-IRremote/Arduino-IRremote**) and expect that it won't be long before someone ports this over to the Pico.

The Arduino demo allows drawing on the LCD by use of the touchscreen – see Screen 4. It reads the SD card and displays the first file found; pressing the 'Files' button on the screen will look for additional files and show their name.

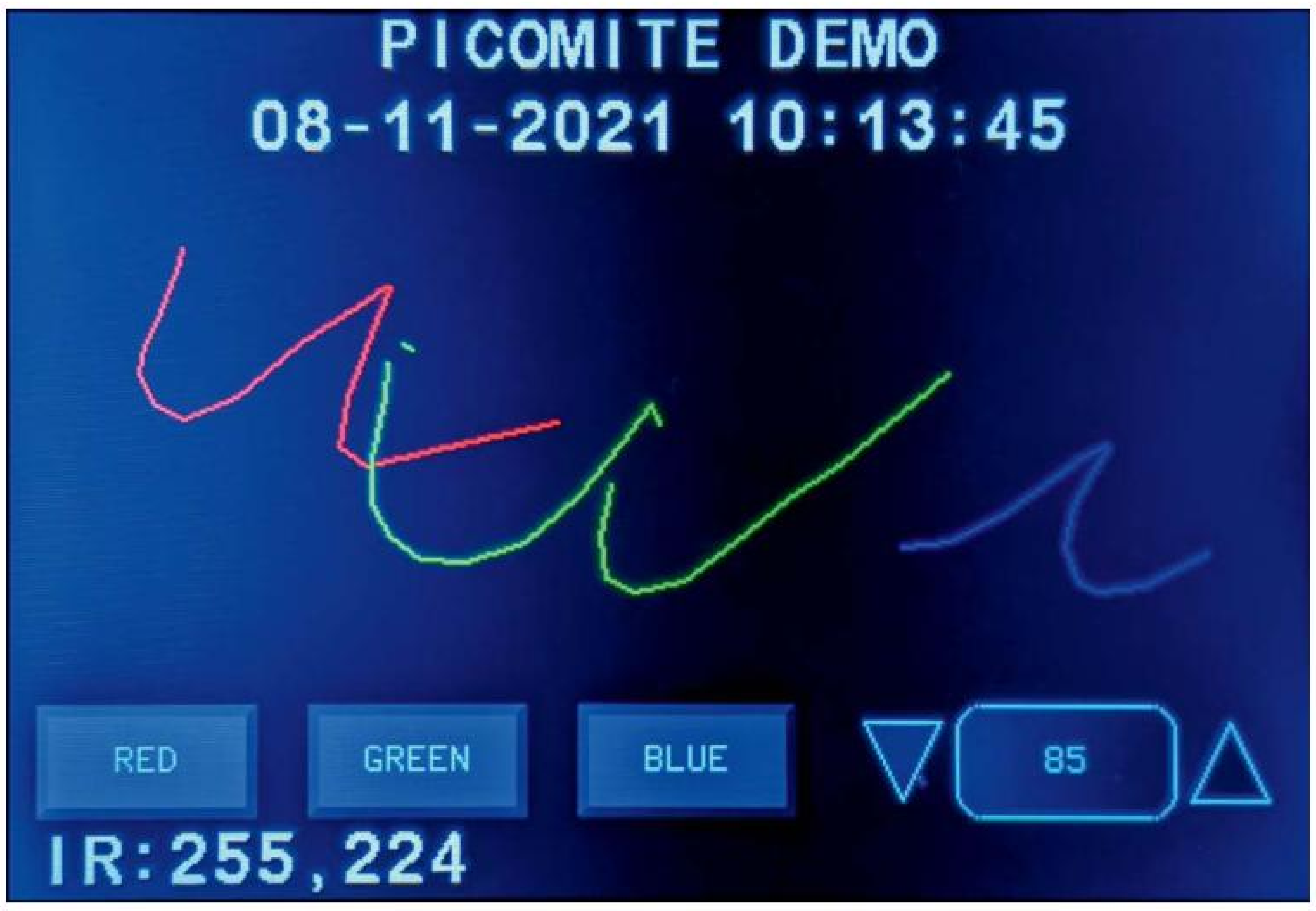
The backlight brightness can be adjusted by the slider at the bottom of the screen. The time found on the RTC chip is displayed. There is sample code in the RTClib library to set the time in the DS3231 chip if that has not been done already.

Sounds are played every time a button is pressed or released; you will need a speaker or headphones connected to hear them. The sounds are sinewaves defined in the **sounds.c** file.

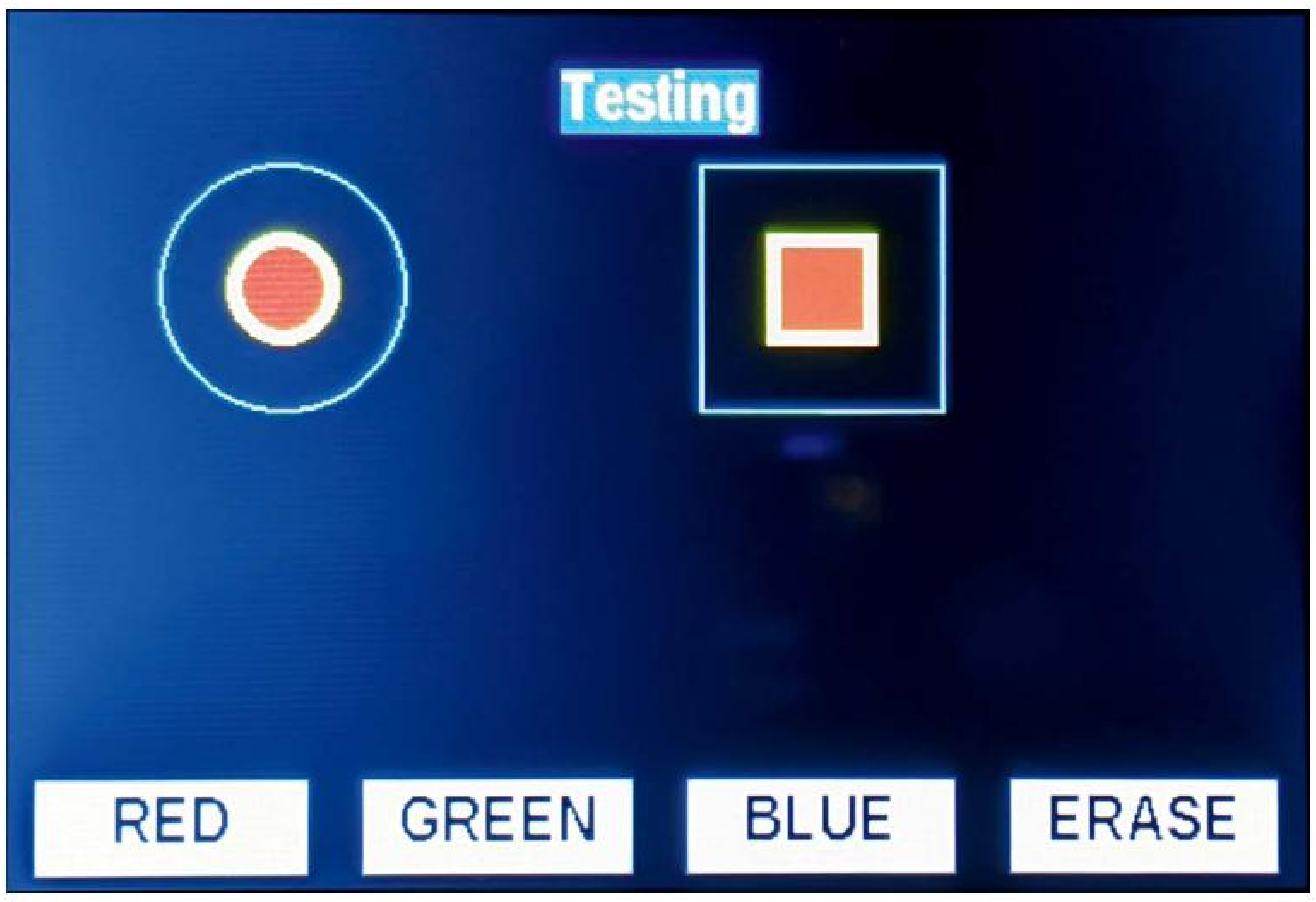
C SDK demo

We found it was a bit trickier to get the C SDK working on its own. We found that many of the required tasks were easier in the Raspberry Pi OS.

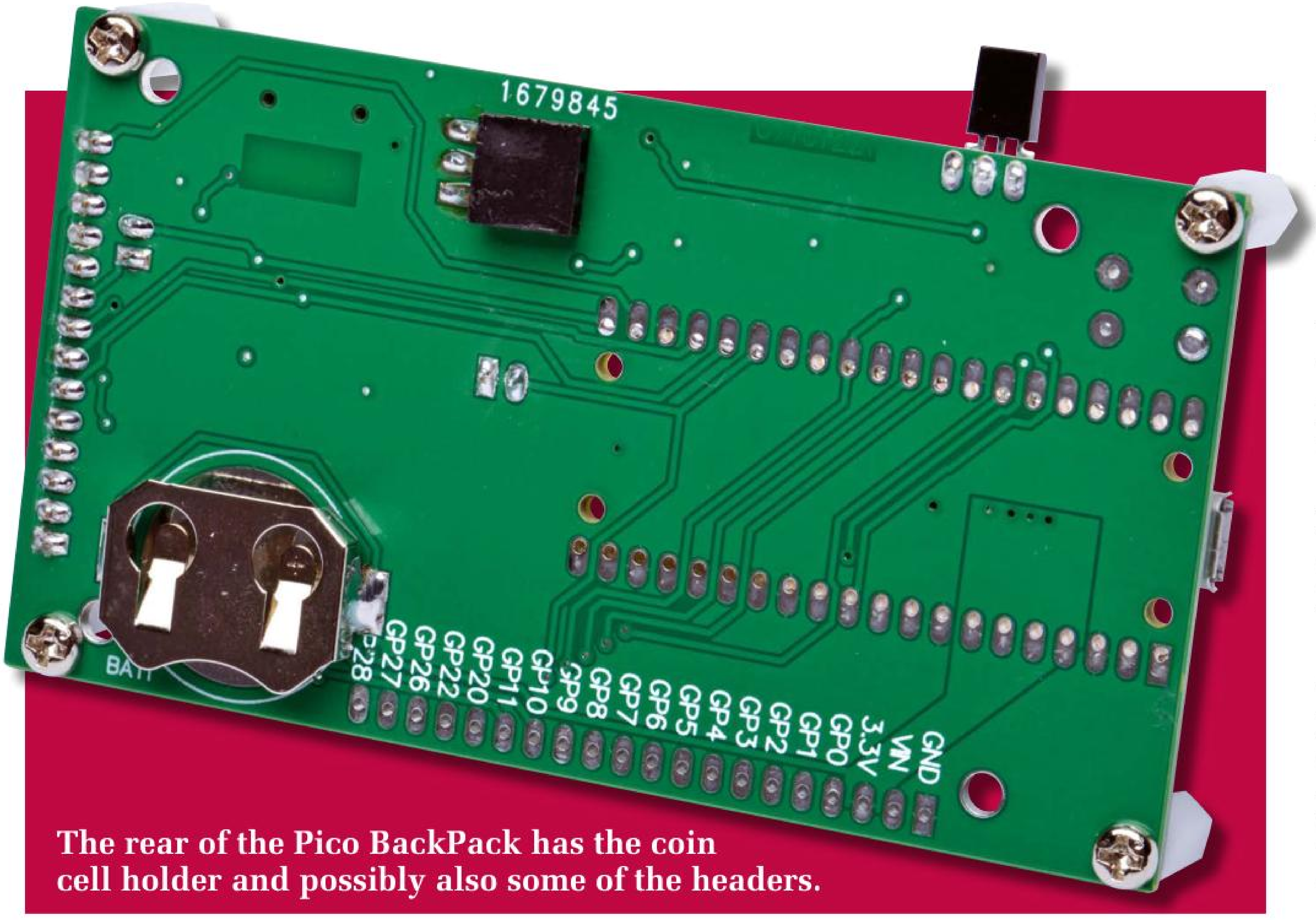
So if you have a Raspberry Pi, we recommend using it to compile projects for the Pico, especially if you want to work



Screen 1: feature-wise, the PicoMite is about on par with a Micromite Plus, although it has fewer pins, more flash memory and more RAM. The demo program allows drawing on the display and playing tones on button presses. It can also decode IR signals that are received.



Screen 2: even though we wrote the display driver in MicroPython, it is still very responsive. MicroPython also provides a file system for the flash storage and has numerous libraries for hardware interfacing.



The rear of the Pico BackPack has the coin cell holder and possibly also some of the headers.

in C. The documentation is written with this in mind, so it makes sense. While a Raspberry Pi is a bit slower than a modern Windows PC, we saved time overall because things seemed to work more often the first time around.

You can load our demo firmware file by putting the Pico into bootloader mode and copying the UF2 file to the RPI-RP2 drive.

It should show the LCD and touchscreen working – see Screen 5. You can draw on the LCD by using the touchscreen. The backlight can be cycled between several brightness levels by the LIGHT button and a sound is produced every time a button is pressed or released.

We haven't found any libraries for SD cards, IR receivers or real-time clock modules to suit the C SDK, so we have not implemented these features. Still, we expect that the rapidly growing community around the Pico could see these developed sooner or later.

One advantage of using C is that the LCD is updated very quickly using the native SPI interface. That could be handy for projects that need rapid screen updates.

Using the C SDK files

It is not easy to create a portable project, even with the Project Generator program. Still, the following method should allow you to build your own projects from our example code.

Use the Project Generator to create a project, being sure to check at least the SPI peripheral option.

We also like to enable the USB console and disable the UART console if we aren't using the USB peripheral for anything else. This makes it easier to send debugging information directly to a virtual USB serial port and frees up the I/O pins that would otherwise be used for the hardware console.

After the project is generated, there will be a .c file in the project folder; it will have the same name as the project you just generated. Copy the contents of the **main.c** file (from our example) over the contents of this .c file, replacing the boilerplate code that the generator has created. Then copy the remaining .c and .h files from our example folder.

There will also be a **CmakeLists.txt** file in the project folder. Open it and find a line like this:

```
target_link_libraries(LCD_TEST
  pico_stdlib)
```

The first item will be the project name. Add a reference to 'hardware_pwm':

```
target_link_libraries(LCD_TEST
  pico_stdlib hardware_pwm)
```

Then save the file. Next, switch to the 'build' subdirectory and run 'nmake' on Windows or 'make' on Linux (including Raspberry Pi OS). If all goes well, the compilation will proceed, and it will create the UF2 file in the build subdirectory. This is the firmware image you can transfer to the Pico to run your new program.

Using the C SDK is quite different to Arduino, BASIC or MicroPython, but it appears that many questions are being asked and answered on the Raspberry Pi forums.

There is a Pico C SDK section of the forum at: **https://bit.ly/pe-mar23-rpi1** and a list of community provided libraries at: **https://bit.ly/pe-mar23-rpi2**

With the Pico being so cheap and already having broad community support for several languages, as well as official (Raspberry Pi Foundation) support for the C SDK and MicroPython, we expect that what is possible will expand quite rapidly.

More features

There are a couple of extra features on the Pico that we should mention, mainly because they are reasonably novel or interesting.

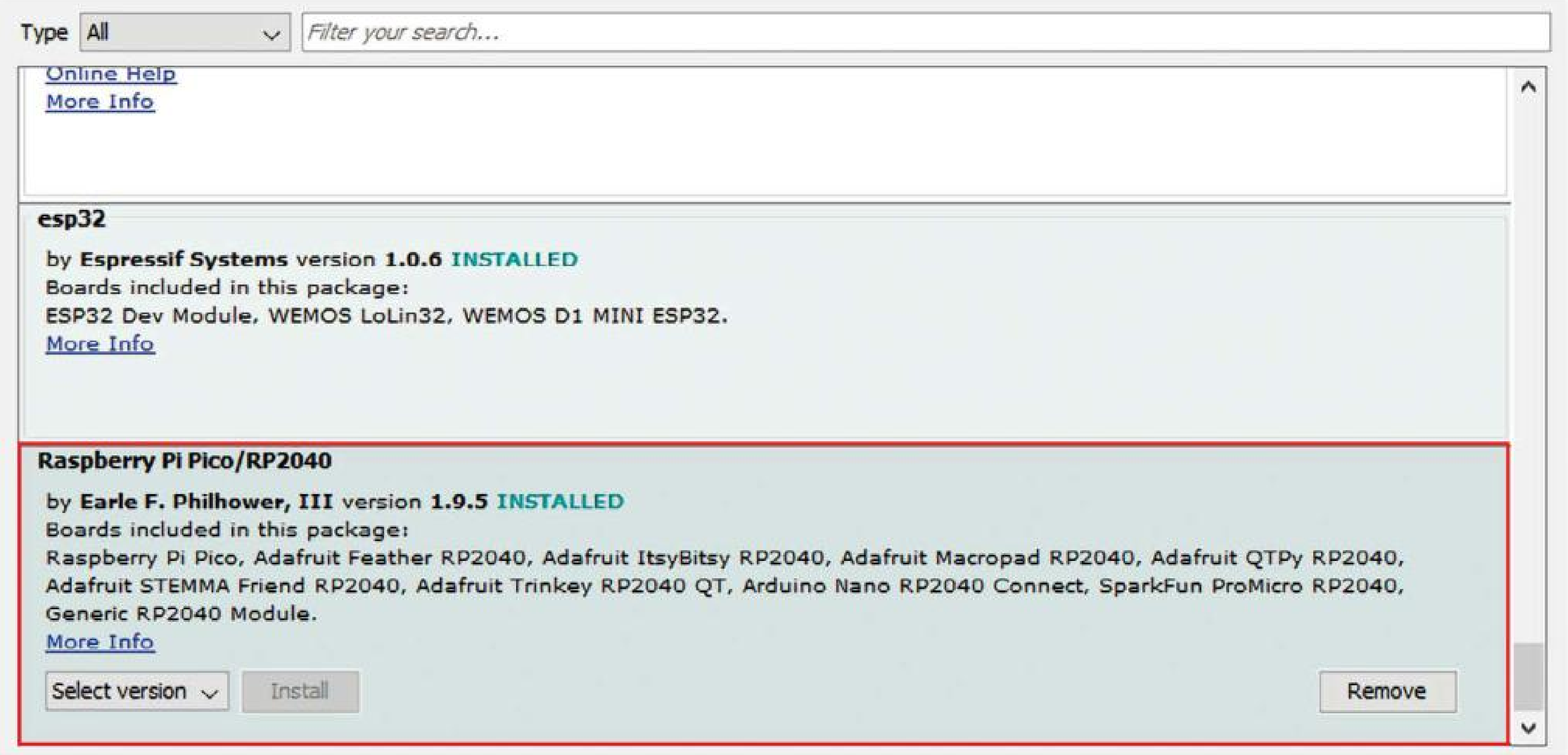
The USB peripheral is not easily usable from PicoMite BASIC or MicroPython. However, the Arduino IDE provides examples to allow the Pico to act as a CDC (serial) device, HID device like keyboard or mouse, mass storage and even a MIDI interface.

The compact Pico is ideal for use as a small USB widget with a dedicated function. Having a dual-core processor also opens up other possibilities, such as real-time monitoring and control.

Dual cores

The RP2040 on the Pico has two ARM processor cores and these can be used in a few different ways. The Arduino IDE and C SDK provide means of running programs on both cores.

Sharing memory between two processors is not always trivial, but it is not too tricky with the Pico. Still, you need to ensure that one core isn't trying to access Flash memory that the other core is erasing, or you'll crash it!



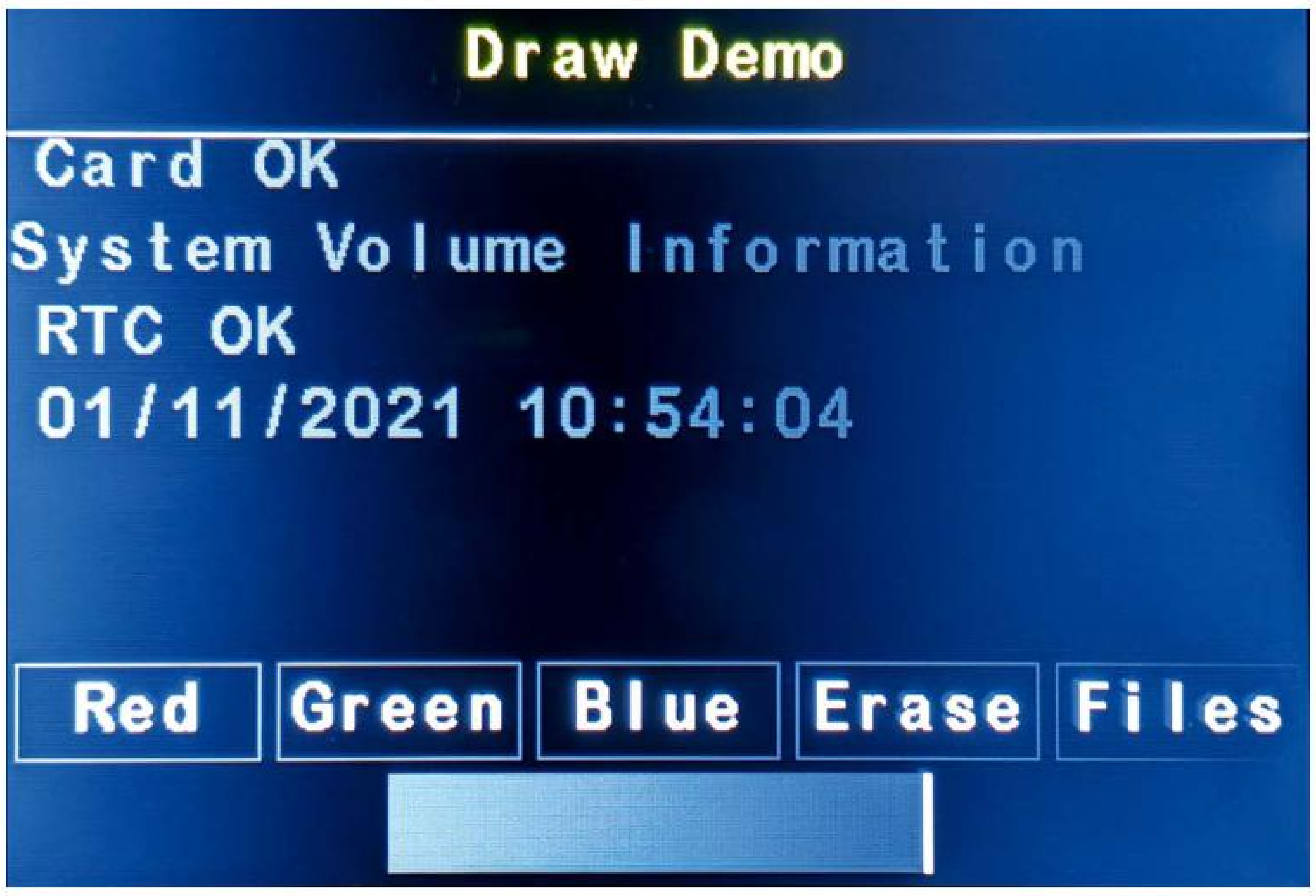
esp32

by Espressif Systems version 1.0.6 INSTALLED
Boards included in this package:
ESP32 Dev Module, WEMOS LoLin32, WEMOS D1 MINI ESP32.
More Info

Raspberry Pi Pico/RP2040

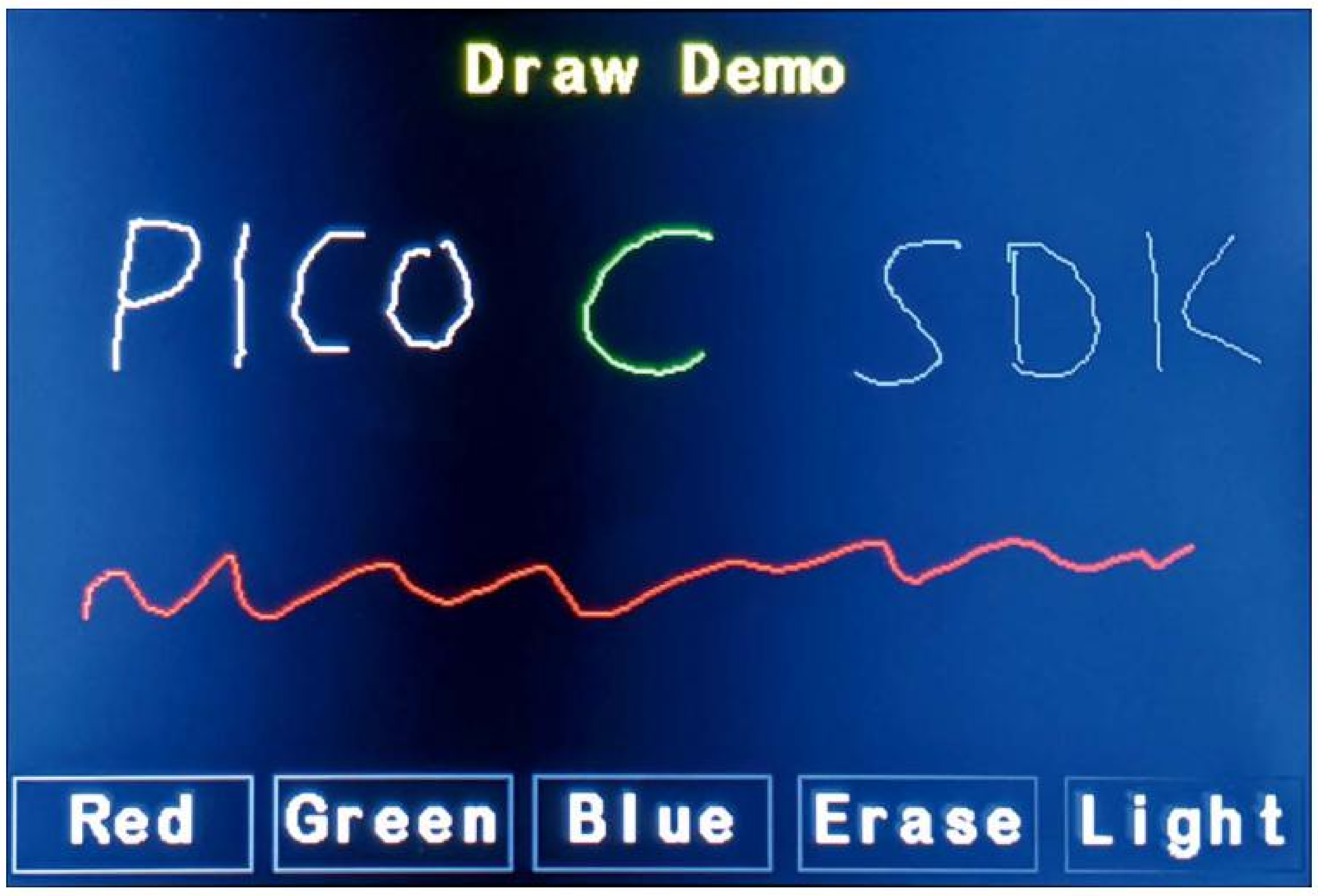
by Earle F. Philhower, III version 1.9.5 INSTALLED
Boards included in this package:
Raspberry Pi Pico, Adafruit Feather RP2040, Adafruit ItsyBitsy RP2040, Adafruit Macropad RP2040, Adafruit QTPy RP2040, Adafruit STEMMA Friend RP2040, Adafruit Trinkey RP2040 QT, Arduino Nano RP2040 Connect, SparkFun ProMicro RP2040, Generic RP2040 Module.
More Info

Screen 3: we're using a custom board profile for the Pico under the Arduino IDE. It can be installed easily, and because it is based on the C SDK, it supports using C SDK functions in projects. It's the bottom-most item highlighted in red.



```
Card OK
System Volume Information
RTC OK
01/11/2021 10:54:04
```

Screen 4: our Arduino demo is one of the more comprehensive tests of the Pico BackPack's features, primarily due to the extensive open-source libraries that are available. You can test the LCD and touchscreen by drawing on the screen, and if you have a speaker connected, it will emit tones when a button is pressed.



Screen 5: the C SDK is trickier to work with than the Arduino IDE or PicoMite BASIC, but it allows for high-performance operation of the Pico if needed. We found it was easily the fastest of the lot when updating the display. Our demo shows off the LCD, touchscreen, backlight control as well as sounding tones when the buttons are pressed.

The Arduino IDE provides simple `setup1()` and `loop1()` functions to allow a second parallel process to start up, while the C SDK provides some low-level interfaces to control this.

MicroPython can use threads to run tasks concurrently using the dual cores, but the dual cores are not exposed at all in PicoMite BASIC.

Storing data in Flash memory

The large, external flash chip on the Pico also means that there is ample onboard storage for large amounts of data. This could be graphics, sounds or lookup tables. It can be accessed as constants from within your program, but some languages provide ways of treating the Flash memory more like a file system.

Another thing worth noting is that the 2MB of Flash available on the Pico is pretty generous for a microcontroller. Like the ESP8266 and ESP32, there are options to use some of this Flash for storage on the Pico in some of these programming environments.

While the removable micro SD card makes it easier to update data by simply popping it out and connecting it to a computer, keep the internal storage in mind if you need a small amount of non-volatile storage.

MicroPython makes native use of this to store files; it's how our two library files and the **main.py** file are stored in our earlier example. The IDE you use should have a way to read and modify the internal storage. There are also methods available to read and write these files from within the MicroPython language.

The Arduino board profile we used earlier supports the LittleFS file system. You can add a separate tool to the Tools menu to manage uploading files to the Flash, and different program and storage profiles can be set to share the available space.

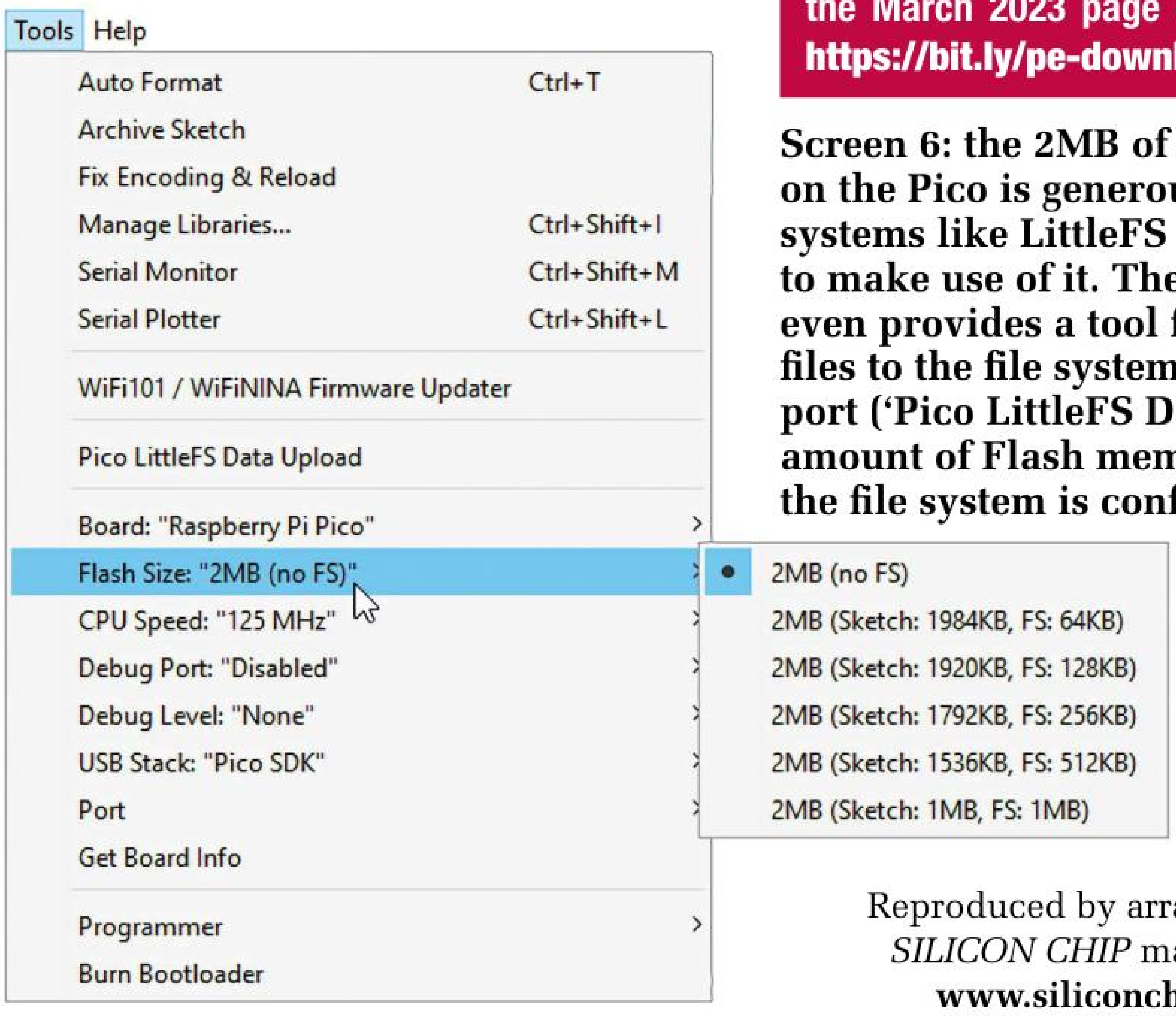
The Pico LittleFS Data Upload is available (after being added) in the Tools menu along with several different memory partitions – see Screen 6. Files to be added are placed into a 'data' folder in the sketch folder and uploaded from there.

There are example sketches under the Examples → Examples for Raspberry Pi Pico → LittleFS menu; the 'FSUpload' example has a link to the upload tool too.

The C SDK provides low-level routines for writing directly to Flash memory, which can be handy if you know what you are doing, but disastrous if you do not. You might overwrite your program! Or perhaps worse, perform too many writes and wear out the Flash.

Still, this is if all you need is a large block of non-volatile storage to store data without needing file type access.

PicoMite BASIC has ten Flash memory slots for programs to be stored and the `VAR SAVE` feature sets aside 16kB for user data to be stored and accessed by a BASIC program.



Tools
Help
Auto Format Ctrl+T
Archive Sketch
Fix Encoding & Reload
Manage Libraries... Ctrl+Shift+I
Serial Monitor Ctrl+Shift+M
Serial Plotter Ctrl+Shift+L
WiFi101 / WiFiNINA Firmware Updater
Pico LittleFS Data Upload
Port
Get Board Info
Programmer
Burn Bootloader

Board: "Raspberry Pi Pico"
Flash Size: "2MB (no FS)"
CPU Speed: "125 MHz"
Debug Port: "Disabled"
Debug Level: "None"
USB Stack: "Pico SDK"

● 2MB (no FS)
2MB (Sketch: 1984KB, FS: 64KB)
2MB (Sketch: 1920KB, FS: 128KB)
2MB (Sketch: 1792KB, FS: 256KB)
2MB (Sketch: 1536KB, FS: 512KB)
2MB (Sketch: 1MB, FS: 1MB)

Screen 6: the 2MB of Flash memory on the Pico is generous, and Flash file systems like LittleFS are a great way to make use of it. The Arduino IDE even provides a tool for uploading files to the file system via the serial port ('Pico LittleFS Data Upload'). The amount of Flash memory set aside for the file system is configurable.

Conclusion

With four different ways of being programmed, a generous amount of RAM and Flash, the Pico microcontroller board is bound to be used in a variety of projects. And it's inexpensive to boot.

Combined with our *Pico BackPack*, we can see this combination being versatile enough to become the core of many different projects in much the same way that the *Micromite Backpack* did.

It's easy to work with the Pico and the *Pico BackPack* using either the Arduino IDE or PicoMite BASIC. We would not be surprised if a *Pico BackPack* programmed in one of these languages found a way into future projects. In fact, we're already planning more than one...

Software

The software and files referenced in this article are available for download from the March 2023 page of the PE website: https://bit.ly/pe-downloads

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- 20 MSa/s, 14 bit continuous streaming
- 1 ppm time base accuracy
- Arbitrary Waveform Generator

SCOPE
CH1
80V
CH2
AWG

Handyscope HS5

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WiFiScope
CH1
CH2
CH3
CH4
80V
Status
LAN
WiFi
USB
Batt

WiFiScope WS6 DIFF

The 1 GSa/s 14 bit quad differential channel High Resolution WiFi Oscilloscope.

Automotive

Automotive Test Scope ATS605004D-XMS
Key specifications

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- Up to 500 MSa/s sampling
- 250 MHz bandwidth
- Up to 100 MSa/s continuous streaming
- Up to 256 Mpoints memory per channel
- 0.25 % DC vertical accuracy, 0.1 % typical
- 1 ppm time base accuracy

CH1
CH2
CH3
CH4
5-15VDC
CMI 1
CMI 2

Automotive Test Scope
ATS605004D-XMS

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Handyscope HS5

Model	Configuration				Order Code	Price £
Handyscope HS5-055				*50 MSa/s base model*	HS5-055	£ 895.00
Handyscope HS5-055-W5				*Extended Warranty*	HS5-055-W5	£ 945.00
Handyscope HS5-055S		*SureConnect*			HS5-055S	£ 957.00
Handyscope HS5-055S-W5		*SureConnect*		*Extended Warranty*	HS5-055S-W5	£1,007.00
Handyscope HS5-055XM	*eXtended Memory*				HS5-055XM	£ 930.00
Handyscope HS5-055XM-W5	*eXtended Memory*			*Extended Warranty*	HS5-055XM-W5	£ 981.00
Handyscope HS5-055XMS	*eXtended Memory*	*SureConnect*			HS5-055XMS	£ 993.00
Handyscope HS5-055XMS-W5	*eXtended Memory*	*SureConnect*		*Extended Warranty*	HS5-055XMS-W5	£1,043.00
Handyscope HS5-110				*100 MSa/s base model*	HS5-110	£ 984.00
Handyscope HS5-110-W5				*Extended Warranty*	HS5-110-W5	£1,034.00
Handyscope HS5-110S		*SureConnect*			HS5-110S	£1,046.00
Handyscope HS5-110S-W5		*SureConnect*		*Extended Warranty*	HS5-110S-W5	£1,096.00
Handyscope HS5-110XM	*eXtended Memory*				HS5-110XM	£1,020.00
Handyscope HS5-110XM-W5	*eXtended Memory*			*Extended Warranty*	HS5-110XM-W5	£1,070.00
Handyscope HS5-110XMS	*eXtended Memory*	*SureConnect*			HS5-110XMS	£1,082.00
Handyscope HS5-110XMS-W5	*eXtended Memory*	*SureConnect*		*Extended Warranty*	HS5-110XMS-W5	£1,132.00

WiFiScope WS6 DIFF

Model	Configuration				Order Code	Price £
WiFiScope WS6 DIFF-200				*200 MSa/s base model*	WS6-DIFF-200	£1,581.00
WiFiScope WS6 DIFF-200-W5				*Extended Warranty*	WS6-DIFF-200-W5	£1,661.00
WiFiScope WS6 DIFF-200G			*SafeGround*		WS6-DIFF-200G	£1,686.00
WiFiScope WS6 DIFF-200G-W5			*SafeGround*	*Extended Warranty*	WS6-DIFF-200G-W5	£1,766.00
WiFiScope WS6 DIFF-200S		*SureConnect*			WS6-DIFF-200S	£1,672.00
WiFiScope WS6 DIFF-200S-W5		*SureConnect*		*Extended Warranty*	WS6-DIFF-200S-W5	£1,752.00
WiFiScope WS6 DIFF-200SG		*SureConnect*	*SafeGround*		WS6-DIFF-200SG	£1,778.00
WiFiScope WS6 DIFF-200SG-W5		*SureConnect*	*SafeGround*	*Extended Warranty*	WS6-DIFF-200SG-W5	£1,858.00
WiFiScope WS6 DIFF-200XM	*eXtended Memory*				WS6-DIFF-200XM	£1,627.00
WiFiScope WS6 DIFF-200XM-W5	*eXtended Memory*			*Extended Warranty*	WS6-DIFF-200XM-W5	£1,707.00
WiFiScope WS6 DIFF-200XMG	*eXtended Memory*		*SafeGround*		WS6-DIFF-200XMG	£1,732.00
WiFiScope WS6 DIFF-200XMG-W5	*eXtended Memory*		*SafeGround*	*Extended Warranty*	WS6-DIFF-200XMG-W5	£1,812.00
WiFiScope WS6 DIFF-200XMS	*eXtended Memory*	*SureConnect*			WS6-DIFF-200XMS	£1,718.00
WiFiScope WS6 DIFF-200XMS-W5	*eXtended Memory*	*SureConnect*		*Extended Warranty*	WS6-DIFF-200XMS-W5	£1,798.00
WiFiScope WS6 DIFF-200XMSG	*eXtended Memory*	*SureConnect*	*SafeGround*		WS6-DIFF-200XMSG	£1,824.00
WiFiScope WS6 DIFF-200XMSG-W5	*eXtended Memory*	*SureConnect*	*SafeGround*	*Extended Warranty*	WS6-DIFF-200XMSG-W5	£1,904.00

Automotive

Model	Configuration	Order Code	Price £
Automotive Diagnostic Kit ADK610004DW	*With ATS610004DW-XMSG*	TP-ADK610004DW	£2,524.00
Automotive Diagnostic Kit ADK610004DW Lite	*With ATS610004DW-XMSG + ATIS Lite*	TP-ADK610004DW-Lite	£2,682.00
Automotive Diagnostic Kit ADK610004DW Pro	*With ATS610004DW-XMSG + ATIS Pro*	TP-ADK610004DW-Pro	£2,928.00
Automotive Diagnostic Kit ADK605004DW	*With ATS605004DW-XMS*	TP- ADK605004DW	£2,195.00
Automotive Diagnostic Kit ADK605004DW Lite	*With ATS605004DW-XMS + ATIS Lite*	TP-ADK605004DW-Lite	£2,352.00
Automotive Diagnostic Kit ADK605004DW Pro	*With ATS605004DW-XMS + ATIS Pro*	TP-ADK605004DW-Pro	£2,598.00
Automotive Diagnostic Kit ADK5004DW	*With ATS5004DW*	TP- ADK5004DW	£1,957.00
Automotive Diagnostic Kit ADK5004DW Lite	*With ATS5004DW + ATIS Lite*	TP- ADK5004DW-Lite	£2,115.00
Automotive Diagnostic Kit ADK5004DW Pro	*With ATS5004DW + ATIS Pro*	TP-ADK5004DW-Pro	£2,361.00
Automotive Diagnostic Kit ADK610004D	*With ATS610004D-XMSG*	TP-ADK610004D	£2,258.00
Automotive Diagnostic Kit ADK610004D Lite	*With ATS610004D-XMSG + ATIS Lite*	TP-ADK610004D-Lite	£2,415.00
Automotive Diagnostic Kit ADK610004D Pro	*With ATS610004D-XMSG + ATIS Pro*	TP-ADK610004D-Pro	£2,661.00
Automotive Test Scope ATS610004D-XMSG	*USB*	ATS610004D-XMSG	£1,798.00
Automotive Test Scope ATS605004D-XMS	*USB*	ATS605004D-XMS	£1,469.00
Automotive Test Scope ATS5004D	*USB*	ATS5004D	£1,549.00

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BY LES KERR

SEMAPHORE SIGNAL

FOR OO-GAUGE MODEL RAILWAYS

This realistic-looking OO-gauge Semaphore has been modelled on a real British semaphore. It has a red/white 'flag' that tilts down by 45° and lights a green LED to signal an oncoming train to continue, or is horizontal with a red light, indicating it should stop. It's made from parts that are relatively easy to obtain, although it requires some access to machine tools and experience to build.

Semaphore signalling was one of the first signalling systems used by railways. Semaphore signals were first patented in England in the early 1840s. They were so successful that they were adopted throughout the railway world. With the advent of coloured lights, they were slowly replaced, but a few remain in use. Adding them to a model railway makes it look very realistic.

British signals come in two forms: lower and upper quadrant. Lower quadrant signals pivot the arm downwards for the off indication (trains can pass), while upper quadrant signals pivot the arm upwards for off. I decided to make a lower quadrant signal as most of the old signal photos I found showed this form.

Current British practice mandates that semaphore signals, both upper and lower quadrant types, are inclined at 45° from horizontal to indicate 'off'.

The British semaphore signal arm consists of two parts: a timber or metal arm (or 'blade') that pivots at different angles and a 'spectacle' holding coloured lenses that move in front of a lamp so the signal is visible at night.

To save having to make coloured lenses, the lamp is replaced with a 3mm red/green bicolour LED in the model. When the arm is horizontal, the red colour is switched on, and when it is down, the green colour is on.

A miniature servo motor moves the signal arm up and down (see Fig.1). The servo collar is connected to the connecting rod (#10), which in turn is connected to the lever (#3). When the servo moves through 45°, the connecting lever does the same. As the connecting lever is joined to the signal blade by the pin (#4), the signal blade follows the movement of the servo collar.

In real life, the height of the signal blade above ground was determined by how far away it could be seen from an approaching train. If you only have a small layout, you can easily lower its height to make it look to scale. This is done simply by reducing the length of the connecting rod (#10) and the mounting pole (#11).

We will present details of both the mechanical and electronic assembly. Just about any hobbyist should be able to assemble the control board as it is a simple single-sided design using all through-hole parts. However, note that making the parts for the mechanical assembly will require some machining experience and some machine tools.

Specifically, you will need a lathe; just about any small one will do, as long as it's built to reasonable tolerances. Most of the machining involves either brass or aluminium, both of which are relatively soft. You will also need a drill press and a good selection of drill bits.

While you can probably get away without it, to produce an exact copy of the Semaphore presented here, you will also need a basic mill with an end mill tool, and the knowledge and ability to use it – or a friend with these skills.

A video showing the Semaphore operating is here: **https://bit.ly/pe-mar23-sem**

Circuit description

The straightforward controlling circuit is shown in Fig.2. The speed at which a servo motor rotates is a function of the servo itself. In the case of the semaphore signal, we need it to rotate much slower than its maximum speed to make it look realistic. This is achieved by feeding a series of pulses to the servo's control terminal, with a time delay between each pulse.

When the up/down switch (S1) is moved to the up position, digital input RB0 of microcontroller IC1 (pin 6) goes high, causing the microcontroller to produce a series of such pulses at its digital output RB1 (pin 7). The result is that the servo motor moves slowly clockwise by 45°. At the same time, digital output RB2 (pin 8) is brought high and output RB5 (pin 11) low, causing the red LED to light.

The 100nF capacitor from pin 6 of IC1 to +5V stops any contact bounce produced by the switch. If the switch is returned to the down position, RB0 is pulled low by the 10kΩ resistor, resulting in another series of pulses from output RB1 that returns the servo motor to its original position. At the same time, output RB2 goes low and output RB5 high, resulting in the LED changing colour back to green.

Servo motors are not as accurate as stepper motors when moving through

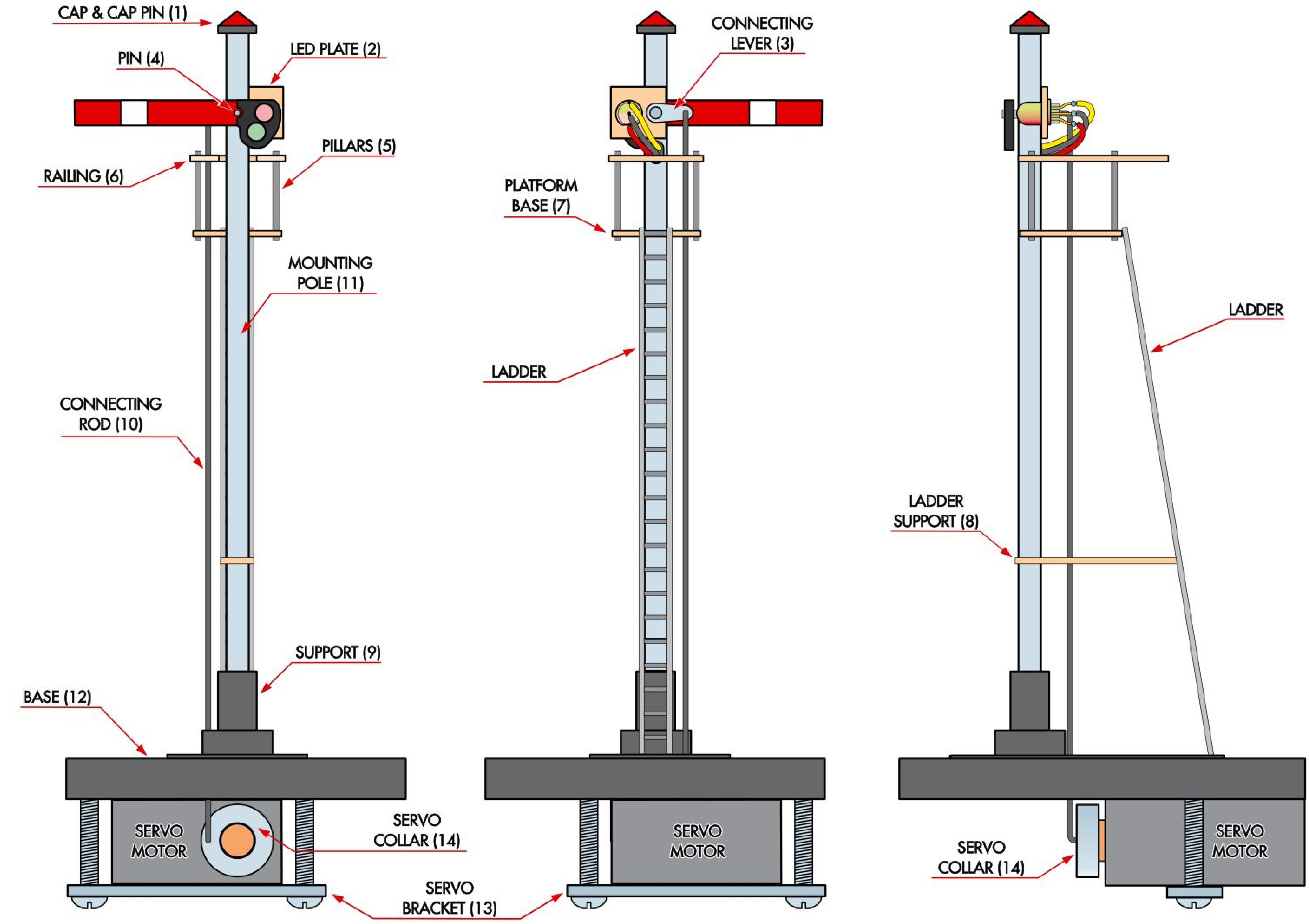


Fig.1: this shows in detail what the Semaphore Signal looks like when it's assembled and where all the pieces go. It's essential to refer to this diagram during each construction step to make sure the parts go together correctly.

a specific angle, being out by as much as 10%. Similarly, any variation in the position of the signal blade hole, the LED plate or the connecting lever and the servo collar can produce errors.

To solve this, two 1kΩ trimpots are provided. The first varies the position of the signal blade in the horizontal position, and the second in the 45° down position. The trim potentiometers vary the voltage on analogus inputs RA0 and RB7 of IC1 (pins 17 and 13, respectively). These feed into IC1's internal analogue-to-digital converter (ADC) which converts the voltages into numbers.

The microprocessor uses these values to determine the pulse widths to produce in the two static positions.

Mechanical assembly

Many of the mechanical Semaphore parts need to be made, and the details of these are shown in Fig.3 (#1-9) and Fig.4 (#10-14). They are made as follows.

#1 Cap and cap pin – I turned the cap from a piece of 6mm aluminium rod by mounting the rod in the three-jaw chuck of a lathe, facing the end (ie, squaring it off) and turning down the diameter to 5.2mm for 5mm. I then cut the 127.6° taper. I reversed the job in the chuck and parted it off to 3mm, then used a centre drill followed by a 2mm drill to a depth of 2mm, taking care not to break through to the taper.

I made the cap pin from an 8mm length of 2mm rod, glued in the hole I drilled in the cap using Loctite GO2. The shape of this item isn't critical, as it varied between different signal manufacturers. Paint the cap assembly red.

#2 LED plate – I made this from a piece of 1/32-inch (0.8mm) thick brass sheet. The distance between the holes is the critical dimension. Drill the holes, then cut the plate to size. Finally, clean up the edges.

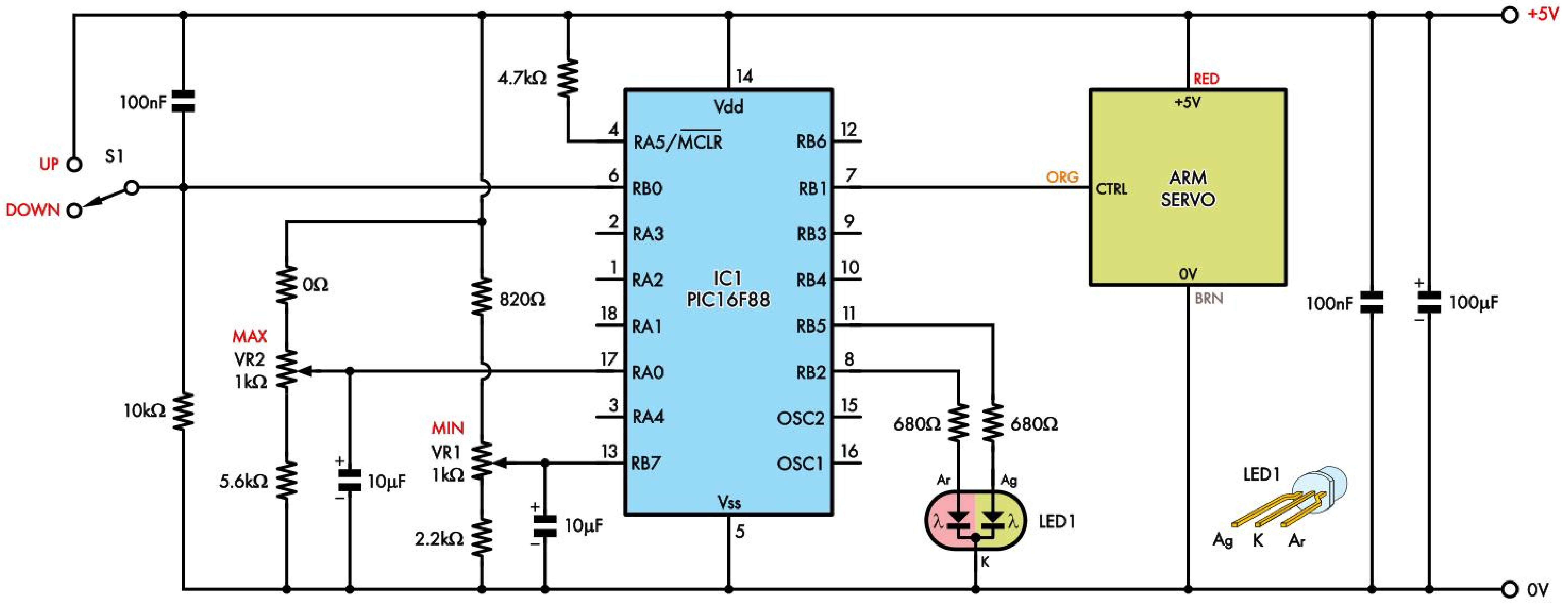
#3 Connecting lever – This was made from a piece of 1/16-inch (1.6mm) thick, 1/4-inch (6.35mm) wide brass. Again, the distance between the holes is critical. Drill the holes first, then cut and file the lever to size. Paint the connecting lever blue-black.

#4 Pin – Cut a piece of 1/16-inch (1.6mm) diameter steel rod to a length of 11mm. Clean up any burrs on the ends.

#5 Pillar (4 required) – Similarly, I made these from 0.8mm diameter (1/32-inch) brass rod cut to 12mm in length. Again, clean up any burrs on the ends.

#6 Railing – This was also made from 0.8mm (1/32-inch) diameter brass rod. I turned a short length of scrap round to 11.2mm diameter and used that as a mandrel to form the curve. A small amount of heat applied by a gas torch makes bending easier.

The finished Semaphore will look like this, with wires connected to the PCB.



Model Railway Semaphore Controller

Fig.2: the control circuit, which runs from a 5V supply, is quite simple. Microcontroller IC1 monitors switch S1 and, depending on its position, sends pulses to the servo to control its angle while lighting either the red or green elements of LED1. Trimpots VR1 and VR2 fine-tune the angles of the flag in the horizontal and down positions, respectively.

#7 Platform base – This is made from a piece of 1/32-inch (0.8mm) brass sheet. Drill all the holes, then cut the plate to size. Next, using a fine saw and file, cut out the square section so that it is a tight fit around the 1/8 inch square mounting pole (see #11 below). Finally, clean up the edges.

#8 Ladder support – This is made from a length of 0.8mm (1/32-inch) diameter brass rod. Use a piece of 1/8-inch (3.2mm) square brass as a mandrel to form the shape. Again, a small amount of heat applied by a gas torch makes bending much easier.

#9 Support – Place a piece of 12mm diameter aluminium rod in the three-jaw chuck of a lathe and face the end. Turn it down to 20mm to make it a slide fit in a 3/8-inch (9.5mm) diameter hole. Use a centre drill followed by a 4.3mm (11/64-inch) drill to bore it out to a depth of 20mm. Next, reduce the end to 5.25mm diameter for 8mm and part it off to length.

Finally, drill and tap the hole in the side for the 2.5mm grub screw. Paint the support blue-black and when dry, then fit the 2.5mm grub screw.

#10 Connecting rod – I made this from 0.8mm (1/32-inch) diameter brass rod. Bend one end of the rod through 90° but only bend the other through about 20°. This is because the rod has to pass through the 2.6mm hole in the 5.5mm-thick base. We will bend it to 90° later in the assembly process. Paint the connecting rod blue-black.

#11 Mounting pole – The mounting pole is made from a length of 1/8-inch (3.2mm) square hollow brass tube. Drill the 1/16-inch (1.6mm) diameter hole at 92mm from the pole end. You can make the slot by drilling two 1mm holes 1mm apart and using a file to remove the remaining metal.

Make sure that the insides of the slot and the insides of each end are free of swarf and are smooth – when we insert the LED wires, we don't want to cut their insulation.

#12 Base – My layout is made on a 2-inch (51mm) thick sheet of polyurethane foam. I buried the signal in the foam so that it was flush with the top of the base. This left a 0.5mm step down all around the Semaphore that I later filled with ornamental grass, so that the base was more in keeping with the scale. Depending on your layout, you might decide to leave out this step down.

The base is made from 6mm aluminium plate. Cut it to size, then drill and tap the required holes. I made the step using an end mill in a milling machine. Paint the base blue-black and when dry, fit the 2.5mm grub screw.

#13 Servo bracket – This is made from 1/16-inch (1.6mm) thick aluminium sheet. Drill the two 3mm holes 29mm apart, then cut it to size. Clean up the edges with a file.

#14 Servo collar – Place a length of 12mm-diameter aluminium bar in the lathe three-jaw chuck, face the end and turn it down to a diameter of 9.8mm for 10mm. Bore it out to a depth of at least 5mm using a centre drill followed by a 4.8mm diameter drill. Part off a 3mm section, transfer this to the drilling machine and drill the 2mm hole for the grub screw. Thread the hole with a 2.5mm tap and fit the grub screw.

Finally, drill the 0.8mm diameter hole exactly 4mm from the centre.

Mechanical assembly

With the parts now made, refer back to Fig.1 to see how they all go together.

The LED plate (#2), platform (#7) and ladder support (#8) are all soldered to the mounting post. Clean, tin and flux the mating surfaces between the LED plate and the mounting post. Insert a temporary pin in the 1/16-inch (1.6mm) hole and use it to align the two pieces. Using a small blowtorch, heat the assembly until you see solder coming out of the joint. File off any excess solder.

Now clean, tin and flux the mating surfaces between the platform and the mounting post. To align the plate squarely, use a small timber cube as a support and clamp it to the mounting post. Using a small blowtorch, heat the assembly until you see solder coming out of the joint.

The next step is to solder the four 12mm pillars into the platform. Do this one at a time using a soldering iron. To keep them vertical in this operation, drill a 0.8mm hole vertically into a piece of scrap timber into which you insert the pin. The railing can then be soldered into place, making sure it is parallel to the platform. File off any excess solder.

Next, clean, tin and flux the mating surfaces between the ladder support and the mounting post. To keep it level, make a small timber cube for it to rest on and clamp that to the mounting post. Using a small blowtorch, heat the assembly until you see solder coming out of the joint. File off any excess solder. The whole assembly can then be painted white.

Signal blade

The signal blade is a PCB, coded 09103222, measuring 31 x 20.5mm and available from the *PE PCB Service* – see Fig.5. Using a small pair of side cutters, carefully remove the blade from the

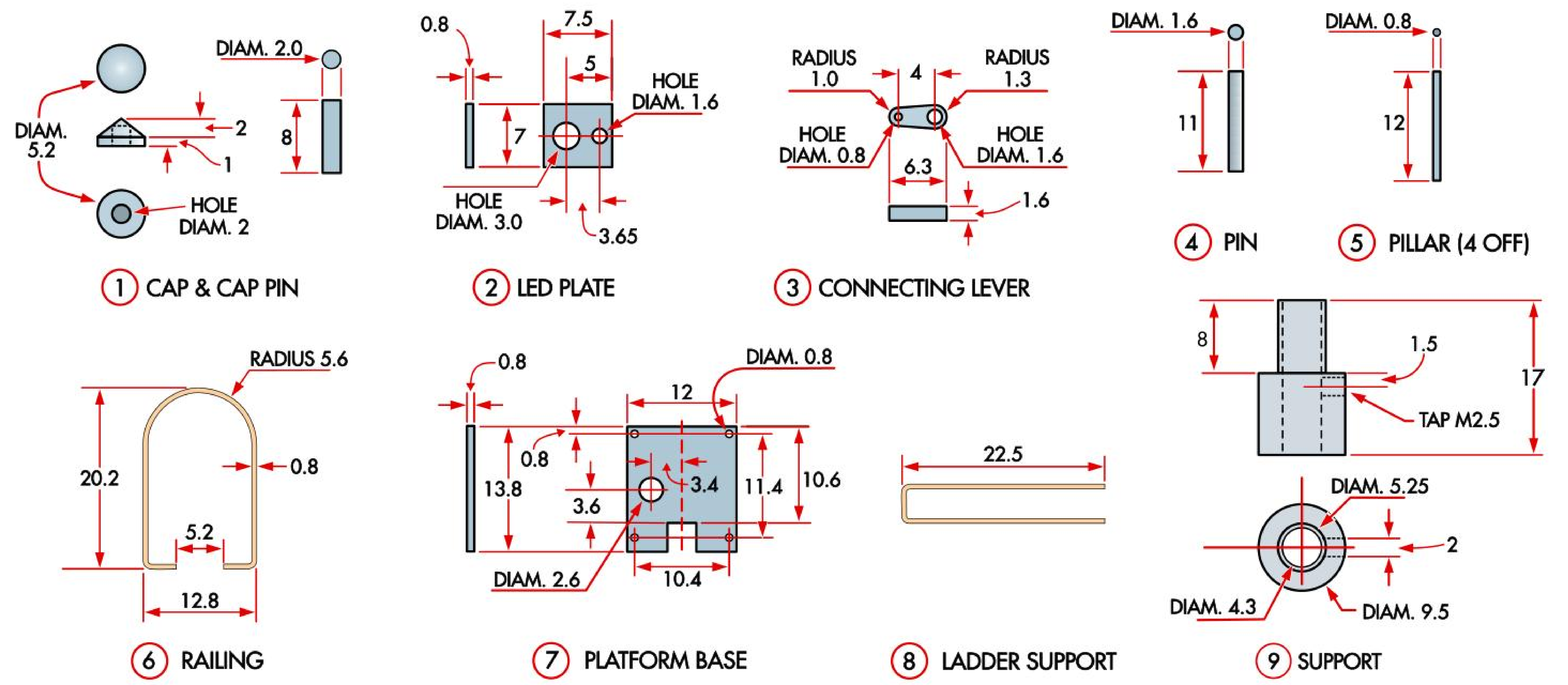

DIAM. 2.0
DIAM. 5.2
8
2
1
HOLE DIAM. 2
① CAP & CAP PIN
0.8
7.5
5
HOLE DIAM. 1.6
7
HOLE DIAM. 3.0
3.65
② LED PLATE
RADIUS 1.0
4
RADIUS 1.3
HOLE DIAM. 0.8
HOLE DIAM. 1.6
6.3
1.6
③ CONNECTING LEVER
DIAM. 1.6
11
④ PIN
DIAM. 0.8
12
⑤ PILLAR (4 OFF)
RADIUS 5.6
20.2
0.8
5.2
12.8
⑥ RAILING
0.8
DIAM. 0.8
12
0.8
13.8
3.4
11.4
10.6
3.6
DIAM. 2.6
10.4
⑦ PLATFORM BASE
22.5
⑧ LADDER SUPPORT
8
1.5
17
TAP M2.5
DIAM. 5.25
2
DIAM. 4.3
DIAM. 9.5
⑨ SUPPORT

Fig.3: this shows the smaller parts (#1-#9) that need to be made. Some can be made on a lathe, while others require a saw, files and drilling. #6 and #8 are made by bending thin cylindrical bar stock on rectangular formers. Note: all dimensions are in mm.

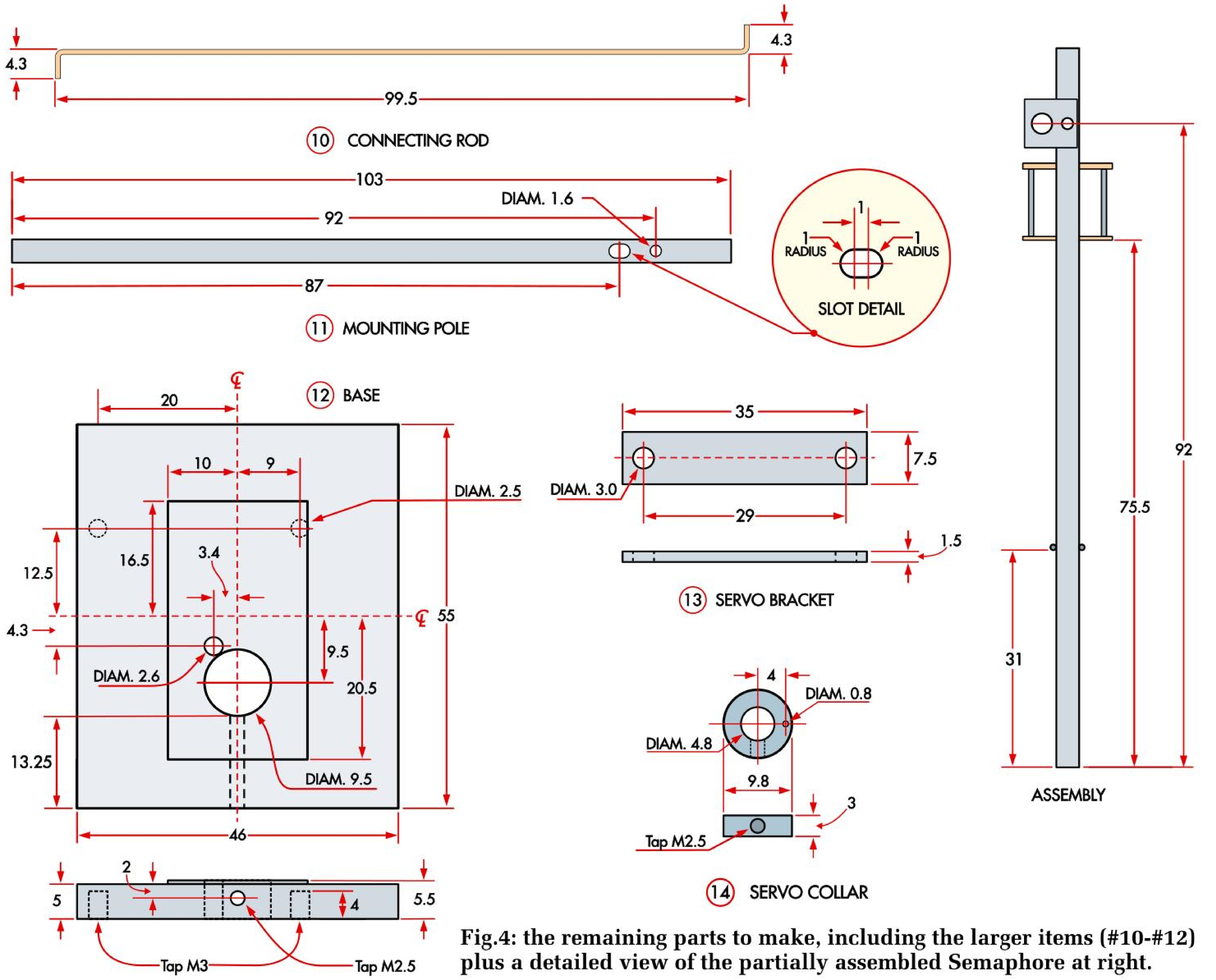

4.3
4.3
99.5
⑩ CONNECTING ROD
103
92
DIAM. 1.6
87
⑪ MOUNTING POLE
1
1 RADIUS
1 RADIUS
SLOT DETAIL
⑫ BASE
20
10
9
DIAM. 2.5
12.5
16.5
3.4
4.3
55
DIAM. 2.6
9.5
20.5
13.25
DIAM. 9.5
46
2
5
4
5.5
Tap M3
Tap M2.5
35
DIAM. 3.0
7.5
29
1.5
⑬ SERVO BRACKET
4
DIAM. 0.8
DIAM. 4.8
9.8
3
Tap M2.5
⑭ SERVO COLLAR
92
75.5
31
ASSEMBLY

Fig.4: the remaining parts to make, including the larger items (#10-#12) plus a detailed view of the partially assembled Semaphore at right.

PCB. You can also snap it at the weak points deliberately created by holes drilled into the supports. Clean up the blade edges with a file.

The PCB is coloured red/white, and you can easily paint the spectacle area (see Fig.6) by masking it and applying spray paint, painting it with a brush, or even using a black permanent marker.

However, if you aren't happy with the PCB colour, or you made the flag some other way, you can download the artwork (Fig.6) from the March 2023 page of the *PE* website (**https://bit.ly/pe-downloads**), print it on a colour printer and cut out the front/back shapes.

Use two-part five-minute epoxy to glue the front shape onto the face of the blade. Once dry, carefully clear the paper from the holes. Glue the rear label on and again remove the paper from the holes.

Control module

The heart of the semaphore signal is built on a single-sided PCB coded 09103221, which measures 51 x 37mm; also available from the *PE PCB Service*. Fig.7 is the PCB component overlay diagram. Start its assembly by fitting the PCB pins, then the IC socket.

The reason for the IC socket is that there is no provision for in-circuit programming. Therefore, the next step is to download the firmware from the March 2023 page of the *PE* website and program the PIC16F88-I/P microcontroller using an external programmer now, before fitting it.

Take care to orient the socket/IC correctly. Next, add the vertically-mounted resistors; you can replace the 0Ω resistor with a wire link. Follow with the capacitors; check that the electrolytic types are the correct way around, with the longer leads to the + symbols. Next, add the 1kΩ trimmer potentiometers and temporarily connect the servo motor and LED1 (as per Fig.8).

Finally, connect the positive of the 5V power pack to +5V and the negative to 0V. Check that all the connections are correct and that there are no dry joints or solder bridges.

At this stage, don't plug in IC1 yet if you have used a socket.

Testing

Switch on the power supply and connect the negative lead of a voltmeter to pin 5 of the IC socket and the positive lead to pin 14. The meter should read +5V. If it reads –5V then the IC socket or IC is the wrong way around.

Switch off the power and insert the IC (if you used a socket), checking that it is correctly oriented. Switch the power on, and the LED should glow green. Short S1's two terminals together and the LED should now glow red, while the servo motor should rotate 45° clockwise (looking at the shaft). Remove the short, and the servo should rotate 45° anti-clockwise while the LED should change to green.

Add the short again and switch off the power. Leave the servo in this position as it will make the final assembly process easier. Now is a good time to give the bottom of the PCB a coat of clear varnish to protect it from corrosion.

Parts List – Semaphore Signal

1 single-sided PCB coded 09103221, 51 x 37mm (controller)
1 double-sided red PCB coded 09103222, 31 x 20.5mm (blade) – **both** PCBs available form the *PE PCB Service*
1 PIC16F88-I/P microcontroller programmed with 0910322A.hex (IC1)
1 5V DC power supply
1 DF9GMS 9g micro servo **[eg, Core electronics SER0006]**
1 18-pin DIL socket (**optional**; for IC1)
2 1kΩ mini top-adjust trimpots (VR1, VR2)
1 3mm red/green LED, three-lead type (LED1) **[element14 Cat 2148798]**
1 miniature SPDT toggle switch (S1) **[eg, Jaycar ST0300]**
2 M3 x 16mm panhead machine screws (for mounting servo)
10 1mm PCB pins
1 10mm length of 1mm diameter heatshrink tubing
various lengths and colours of light-duty hookup wire
1 tube of Loctite GO2 adhesive
1 tube of Tarzan's Grip or similar adhesive

Capacitors

1 100µF 16V electrolytic
2 10µF 16V electrolytic
2 100nF 50V multi-layer ceramic

Resistors *(all 0.25W 1% metal film)*

1 10kΩ
1 2.2kΩ
1 5.6kΩ
1 820Ω
1 4.7kΩ
2 680Ω

Mechanical parts

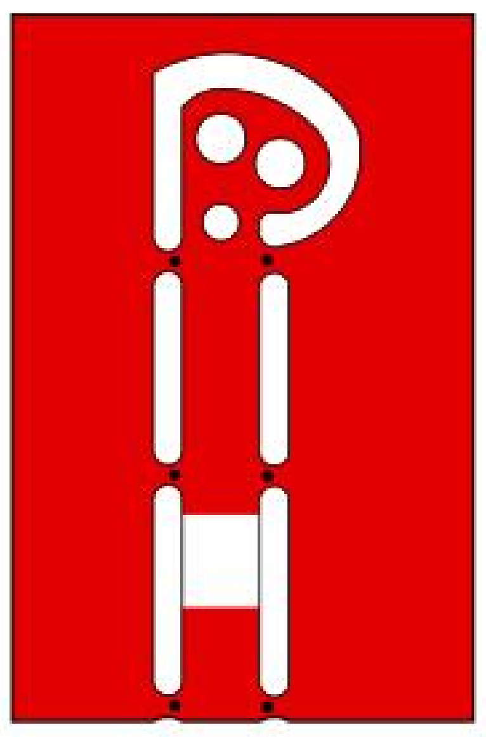
1 300mm+ lengths of 0.8mm (1/32-inch) dia brass rod
1 20mm+ length of 1.6mm (1/16-inch) diameter steel rod
1 20mm+ length of 2mm diameter aluminium rod
1 20mm+ length of 6mm diameter aluminium rod
1 40mm+ length of 12mm diameter aluminium rod
1 103mm length of 3.2mm (1/8-inch) square hollow brass tube
1 20mm+ length of 1.6mm (1/16-inch) thick, 6.53mm (1/4-inch) wide brass bar
1 20 x 20mm rectangle of 0.8mm (1/32-inch) thick brass sheet
1 46 x 55mm rectangle of 6mm-thick aluminium sheet
1 35 x 7.5mm rectangle of 1/16-inch (1.6mm) thick aluminium sheet
1 OO-scale ladder
3 2.5mm grub screws

Final assembly

Refer back to Fig.1 during final assembly to see how the Semaphore goes together.

1. Push the red/green LED into the LED plate. Before trimming the leads as short as possible, note which is the shortest as this connects to the red LED. The centre lead is the common, and the other goes to the green LED.
2. The connecting wires must be very fine to fit through the mounting pole. I found suitable wires in an old computer mouse connecting cable. I selected red, yellow and black and made them about 300mm long. Using a fine-tipped soldering iron, connect the red wire to the red LED terminal, the yellow wire to the green LED terminal and the black wire to the common (middle) terminal.
3. Cut a 5mm length of 1mm diameter heatshrink tubing and slide it over the wires. Insert the wires one at a time into the post until they protrude from the end. Be very careful not to strip the insulation off in this process. Straighten up the wires and shrink the tubing down over the exposed portion of the wires using a heat gun.
4. Insert #4 (the 1/16in [1.6mm] diameter steel pin) into the signal blade and lock it into place using Loctite GO2. When dry, slide the assembly into the mounting pole (#11).
5. Push the support (#9) into the base (#12) with the grub screw in the support on the right-hand side when looking at the front of the signal. Tighten the grub screw in the base.
6. Push the three wires at the bottom of the post through the hole in the support, then push the post into the support and lock it temporarily in place using the grub screw in the support.
7. Take the connecting rod (#10) and push the end with the 20° bend up through the base and platform to the signal blade height. Use pliers to increase the 20° bend to 90°.
8. Insert the end of the connecting rod into the 0.8mm (1/32in) hole in the connecting lever (#3) and push the pin attached to the signal blade into the 1.6mm (1/16-inch) hole in its other end. With the signal blade horizontal, adjust the position of the connecting lever so that it is parallel to the axis of the signal blade. Lock the connecting lever temporarily in place with a blob of glue.
9. Attach the servo bracket (#13) to the base using the two 16mm M3 screws. Align the servo motor as shown in Fig.1, and attach the servo collar to the shaft with the grub screw hole at the bottom.
10. Loosen the grub screw holding the mounting post in place. Slide the servo motor assembly under the retaining bracket. By adjusting the height of the post, you should be able to align the connecting rod with the 0.8mm (1/32in) hole in the servo collar. Push the end of the connecting rod into the collar.
11. Move the servo until the connecting rod is vertical, then lock it in place by tightening the screws. Adjust the column height until the connecting lever at the top of the signal is horizontal. Tighten the grub screw holding the mounting post in place and the grub screw in the servo collar.
12. Check that the signal blade is parallel to the front of the mounting base. If it is not, loosen the grub screw in the base and rotate the post until it is. Tighten the grub screw.

Fig.5: the semaphore flag is too small for most PCB manufacturers to make by itself, but they will make this larger PCB which can be snapped or cut apart (at the holes represented by black filled circles) to give you something very close to the correct flag shape. After cutting or snapping it out, all you have to do is file the top and bottom edges flat.



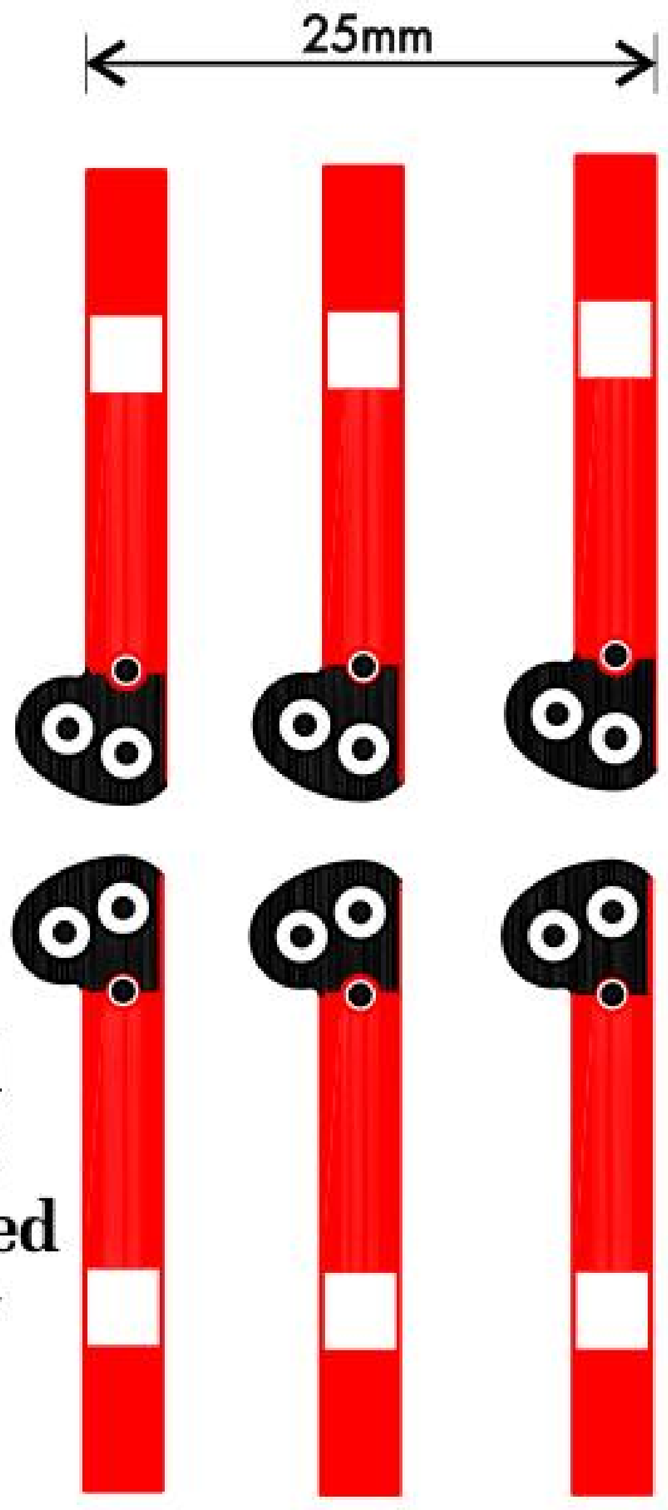


Fig.6: this artwork can be downloaded, printed, cut out and glued to the flag if it isn't already coloured or you aren't happy with the colour or surface finish.

Wiring

Wire up the signal as shown in the wiring diagram, Fig.8. Check this before applying power, as reversing the supply polarity will destroy IC1.

Then, with the switch closed, apply power. The LED should glow red, and the signal blade should be horizontal. Open the switch; the LED should light green and the signal blade should move down about 45°. Operate the signal several times to make sure it changes over smoothly and that nothing is binding. Check the tightness of the three grub screws and the servo screws.

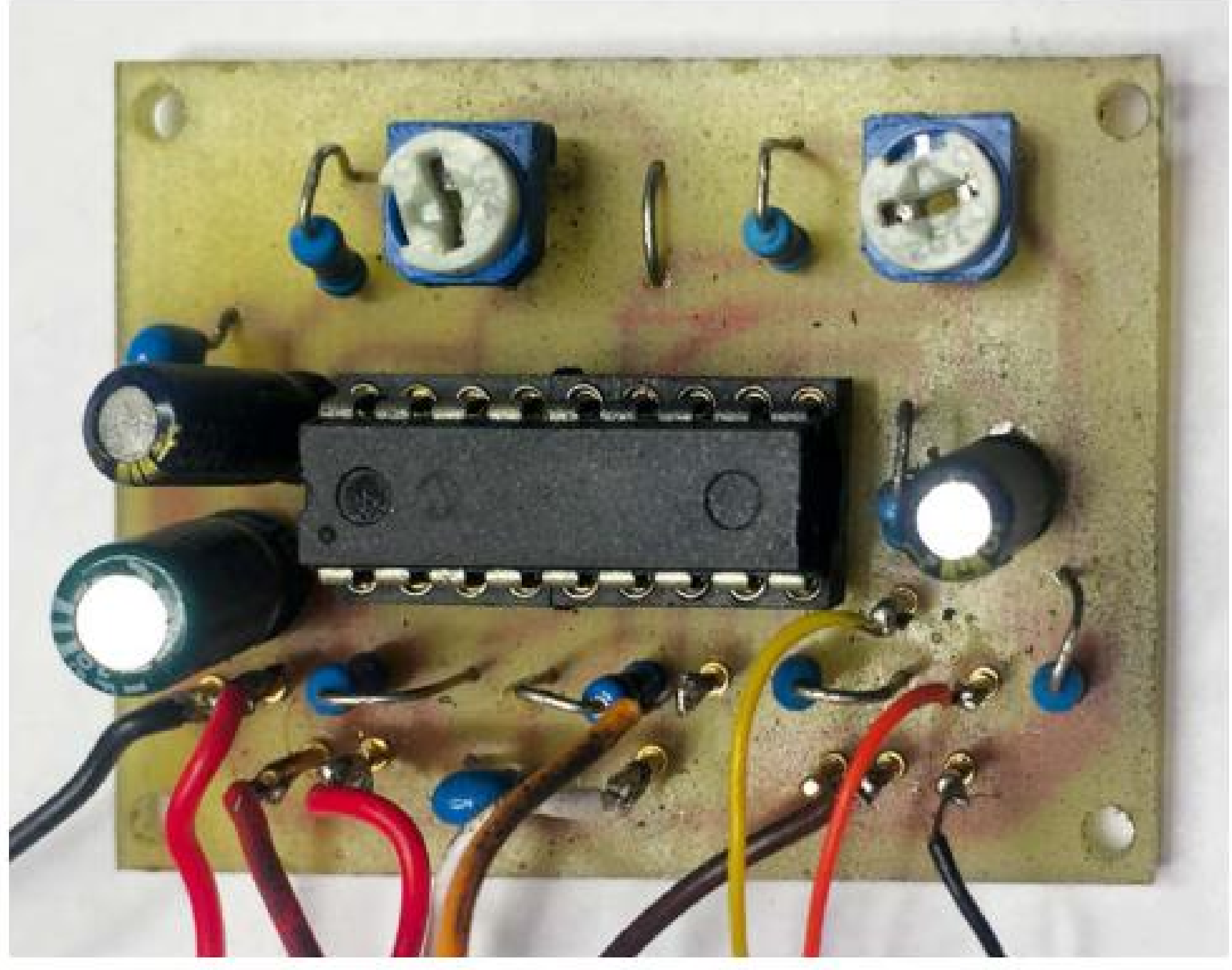
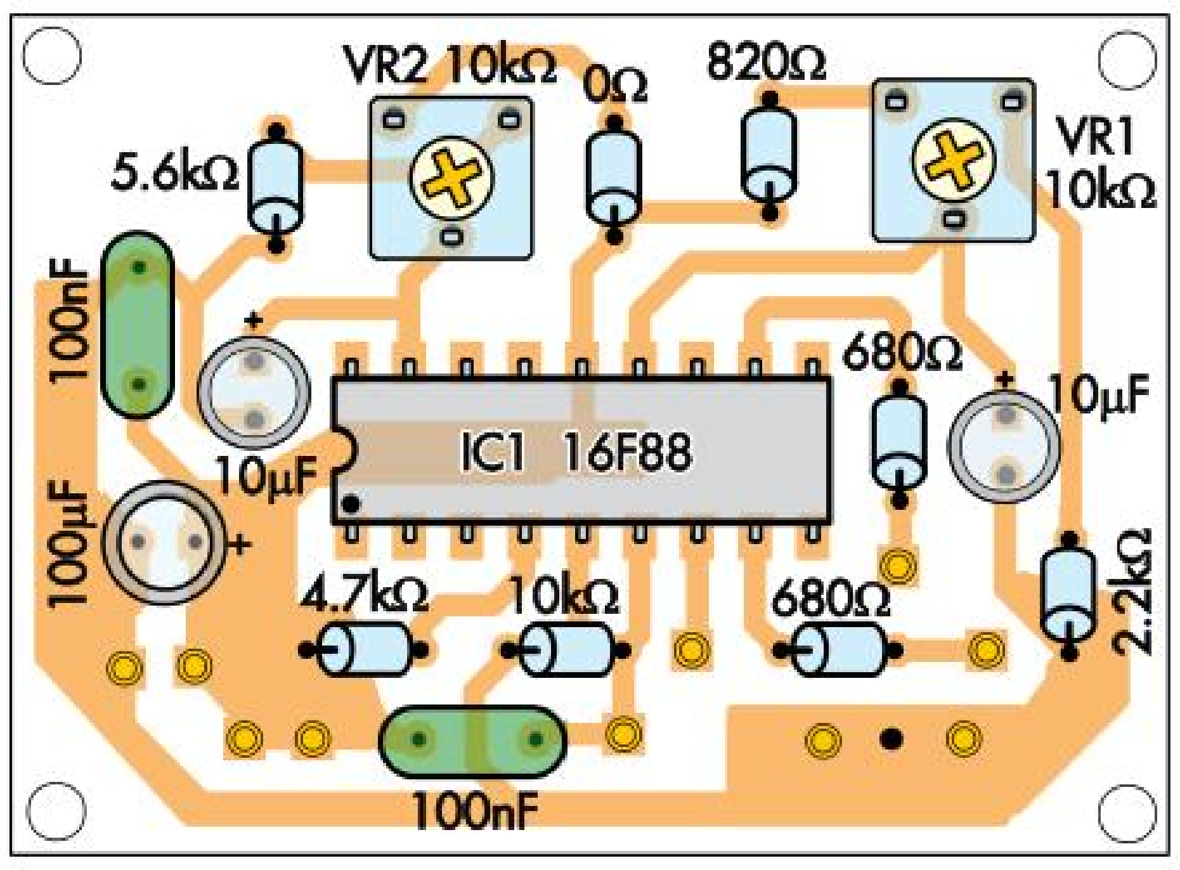


Fig.7: it shouldn't take long to assemble the PCB as it only has a handful of parts on it. Make sure the chip is programmed first if you're going to solder it directly to the board and watch the orientations of the electrolytic capacitors (the longer leads are positive).



The two potentiometers on the PCB allow you to fine-tune the position of the two holes over the LED in the signal blade. The potentiometer closer to the LED connections on the PCB (VR1) adjusts the position of the signal blade in the horizontal position and the other (VR2) in the down (45°) position. Once you are happy with the blade position, use a drop of Loctite GO2 to glue the connecting lever in place.

Fitting the cap and ladder

Attach the red cap and pin assembly into the top of the mounting pole using Loctite GO2.

Take an OO-scale ladder length and paint it blue-black. When dry, lay the ladder up against the platform support and check that the top rung is level with the platform. Cut it to size and use Loctite GO2 to glue the ladder to the platform and support. I deliberately didn't glue the ladder to the base, as that would stop the post assembly from being adjusted later.

Using it

The Semaphore could be combined with a level crossing, such as my design (July 2022), or you could use it on its own, such as before a switch or a station.

The simplest method is manual control. Position a toggle switch at a convenient location in the layout. With the Semaphore in the stop (horizontal) position, manually stop the train in front of it. Then, switch the Semaphore off at an appropriate time, and the train can move away.

There are also methods to automate it. For example, if used near a level crossing, you could arrange for the Semaphore to usually be in the stop (horizontal) position and then automatically switch to the down position when the level crossing boom gates are fully down. It could change back to the stop position as soon as the boom gates start to lift.

All you need to organise this is to have a microswitch or reed switch arranged so that it is open when the boom gates are fully down and closed the rest of the time.

If you can't easily do that, the other option is to use a delay circuit that's triggered by the same signal that activates the level crossing. Set the delay so that it closes a set of relay contacts or activates an open-collector/drain transistor after the boom gates have had a chance to fully lower.

Use those contacts or that transistor to trigger the Semaphore into its off position, and arrange it so that the contacts open or transistor switches off as soon as the Level Crossing trigger switches off.

You could also consider positioning a reed switch under the tracks and placing a magnet in the train. This way, when the train pulls to a stop in front of the Semaphore, it triggers a delay circuit that disables the Semaphore signal after a couple of seconds. It would need to hold it off until the train has passed, possibly sensed by a second reed switch. I'll leave the details of that arrangement as an exercise for the reader.

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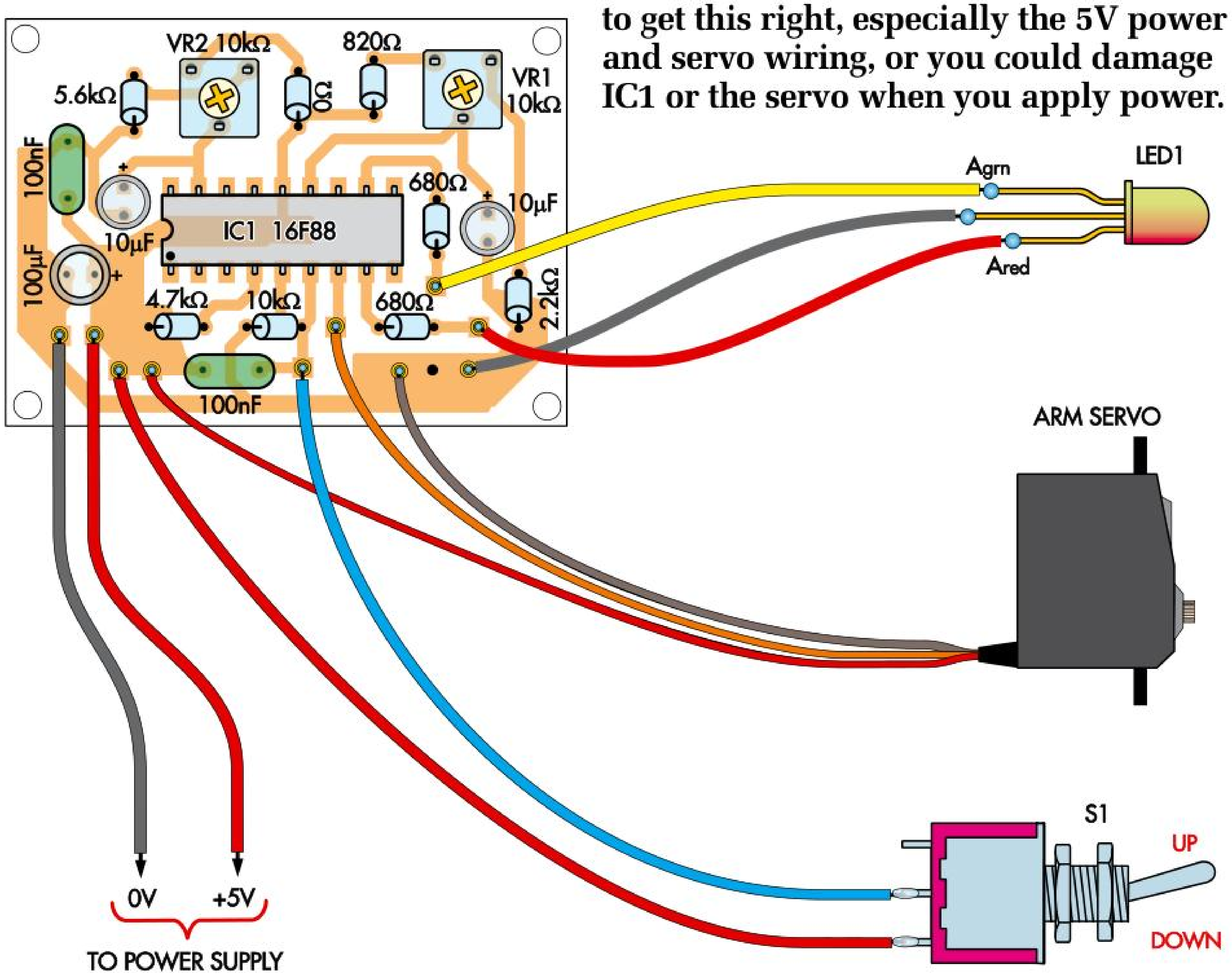
Fig.8: once you've assembled the Semaphore and the control PCB, here is how to wire them up. Be very careful to get this right, especially the 5V power and servo wiring, or you could damage IC1 or the servo when you apply power.



AUDIO OUT

AUDIO OUT
L R

By Jake Rothman

Handyscope HS5 USB oscilloscope review

I wouldn't normally review a digital oscilloscope; after all, I'm very much an analogue specialist. However, the more I thought about it, the more I realised that if I can successfully run a USB oscilloscope, then probably anyone can! With that in mind, here are my impressions of the Handyscope HS5 USB oscilloscope, as shown in Fig.1.

The Handyscope HS5 is made by TiePie engineering, a Dutch company developing and selling computer-controlled measuring instruments. It is sold in the UK by iTP (innovative Technology Projects Ltd), based just outside Cambridge. Just to be clear, I'm reviewing a standard for-sale model. It's not a freebie and I had to return it after I completed the article.

Analogue angst?

In the past, I've dismissed most affordable (£500-£1300) digital scopes with disdain. They often have just 8-bit vertical resolution and awful 640-line low-res LCD screens. My field – analogue audio – is all about smoothness in amplitude. It's impossible to see tiny power amp crossover and converter non-linearities when the glitches you are looking for are smaller than the visual steps on the scope. For this reason, many analogue audio engineers are still wedded to their old Tektronix and other cathode-ray tube oscilloscopes (CROs). Their vertical resolution is only limited by the noise in the Y amplifiers and beam width.

Another factor is modern digital scopes can have huge bandwidths, sometimes up to several GHz. This is quite unnecessary for analogue audio – 20MHz is more than enough. In other words, while this GHz-capability has to be paid for, it is never used in audio. Last, but not least, in my experience, the biggest digital scope issue for audio enthusiasts is obtaining 16-bit vertical resolution, which I think is the minimum usable for audio work. I remember using an impressive Keysight Agilent MSOS804A digital scope at the university where I taught. It was the first one I'd found satisfactory for audio work, but imagine my disappointment when I found back then it cost £60k.

Despite my general scepticism, I've always known that there are some things only digital scopes can do, things that are very useful for audio. For example, transient capture and data logging, which are great for fault and thump analysis. Plus, nowadays, I can see that screen resolution issues can be cheaply overcome by using a modern high-resolution computer monitor. In other words, a USB scope, in conjunction with a computer could potentially create a very satisfactory system for audio work.

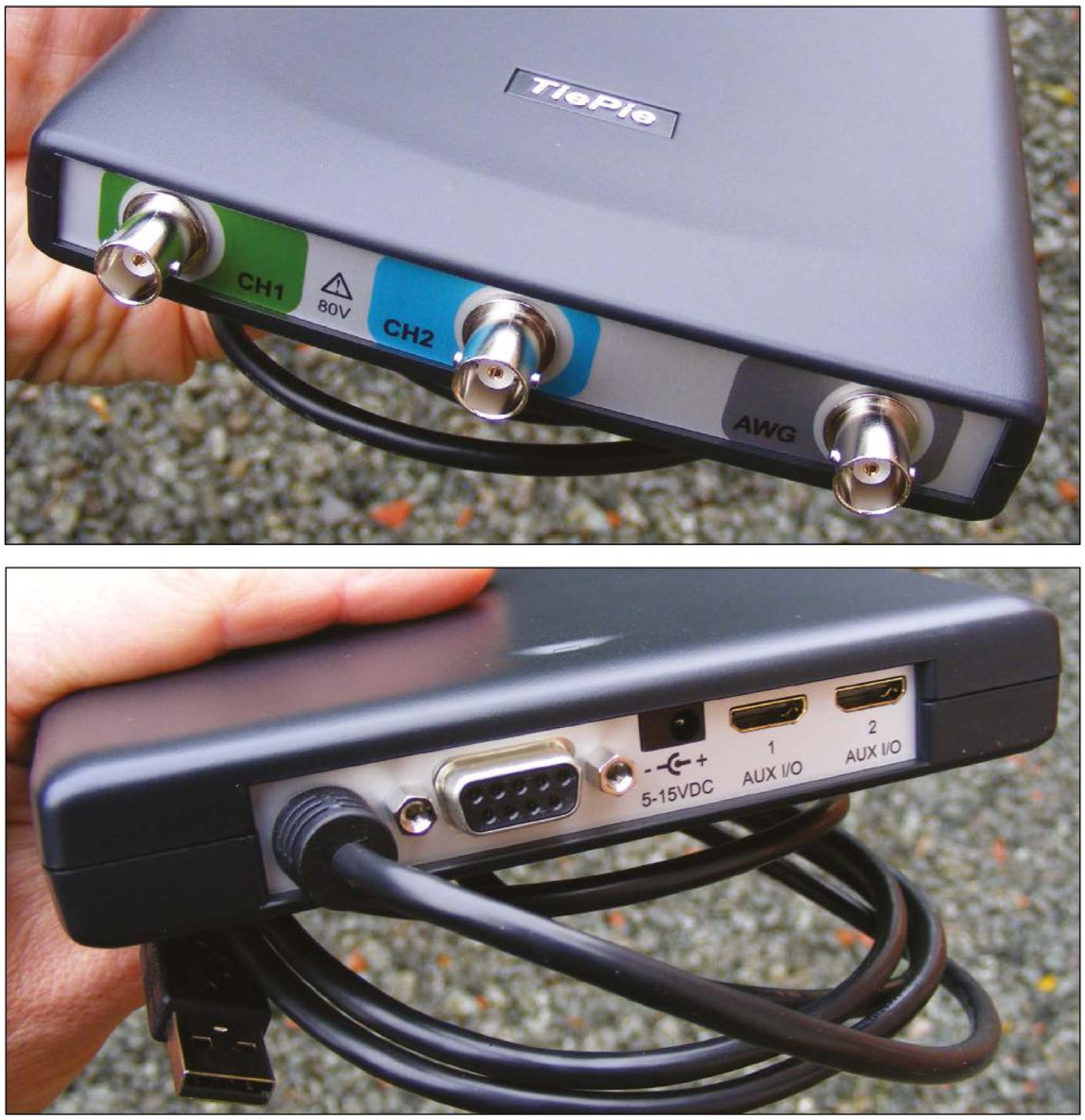


Fig.1. An understated box that does a hundred things... once you've learned to use the software. The rear panel has a captive USB lead and a power socket for the supplied power supply. The PSU is worth using because then no current is drawn from the computer. The Handyscope draws 130mA without the software running and 610mA in normal scope mode. This rises to 860mA with the signal generator switched on with no load. The AUX sockets are for combining multiple Handyscopes. The 9-pin D connector has internal and external clock pins, generator stop and start, power in and out, I^2C serial communication bus and some low-voltage TTL connections.

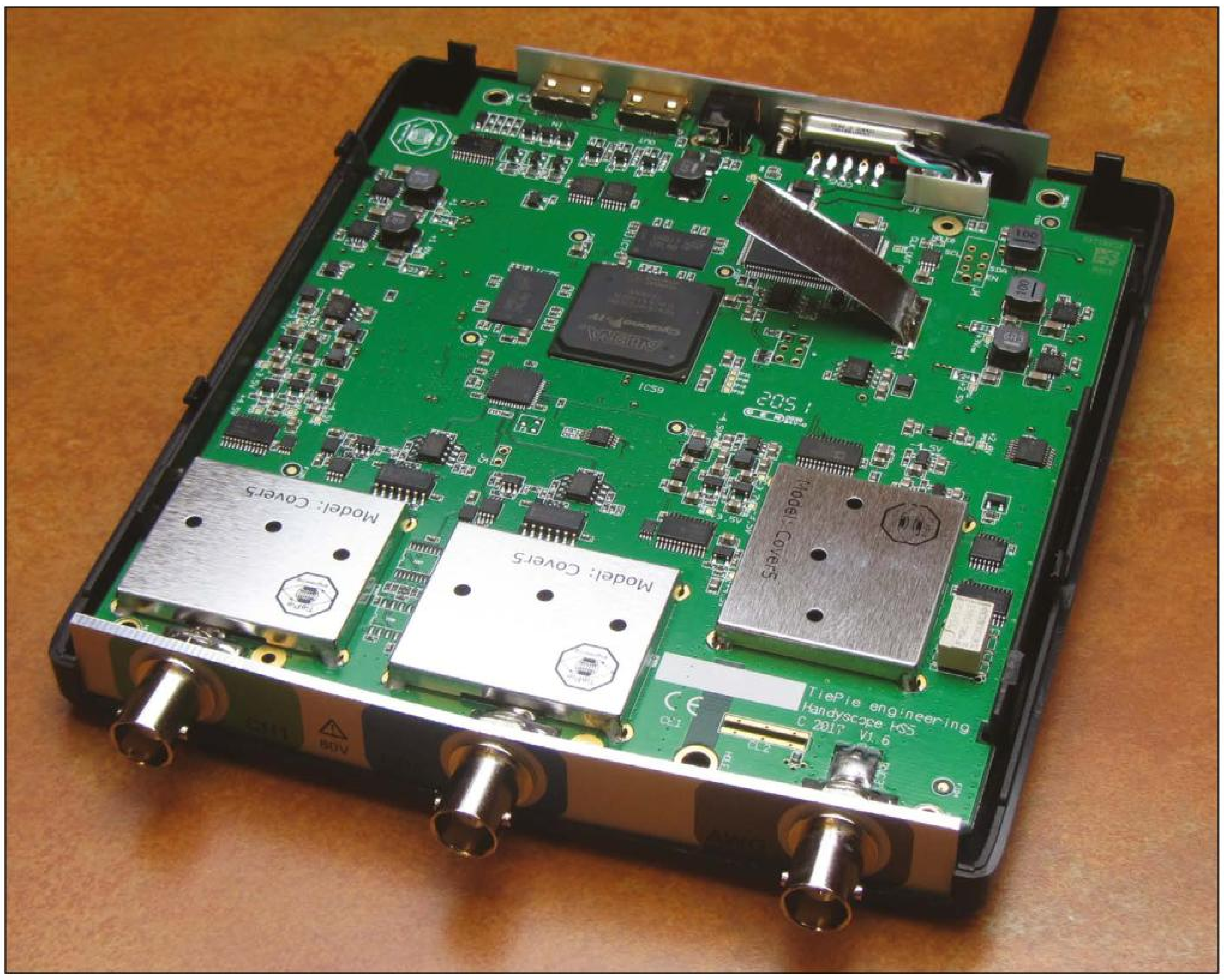


Fig.2. No, I didn't open it! Erik at TiePie sent me this internal shot – solid engineering. Note the metal screening cans on the input stages and signal generator sections.

While hunting for a possible digital scope I noticed that TiePie's HS5 is a 16-bit resolution instrument and that it also comes with spectrum analyser capability and an internal signal generator, where almost any test waveform could be set up. I've been in the market for a spectrum analyser, having been disappointed with the one on my Audio Precision analyser and other specialised bench units, so these features clinched it for me and I asked for a loan unit to test and review. I'm pleased to say that after-'sales' support was good – TiePie replied to all emails and phone calls in a fast and friendly manner. In particular, Erik Tigchelaar at TiePie happily dealt with some tricky technical questions. He even sent me a photo of the scope's internals, revealing a neat, highly professional construction (see Fig.2).

Unboxing

The unit includes two probes with all the standard accessories such as spring clips. There's a USB power lead along with the main computer USB lead – the latter is permanently connected to the unit. A nice touch is two high-quality *printed* manuals, one for general use and the other hundred-pager for the scope's unique Multi Channel software. A typical setup for the scope is shown in Fig.3. One thing I miss is some physical medium, such as a CD, for the essential software. Living in a rural area that has occasional network blackouts, it's an omission that makes me feel insecure. Still, it's not that difficult to make one's own offline backups.

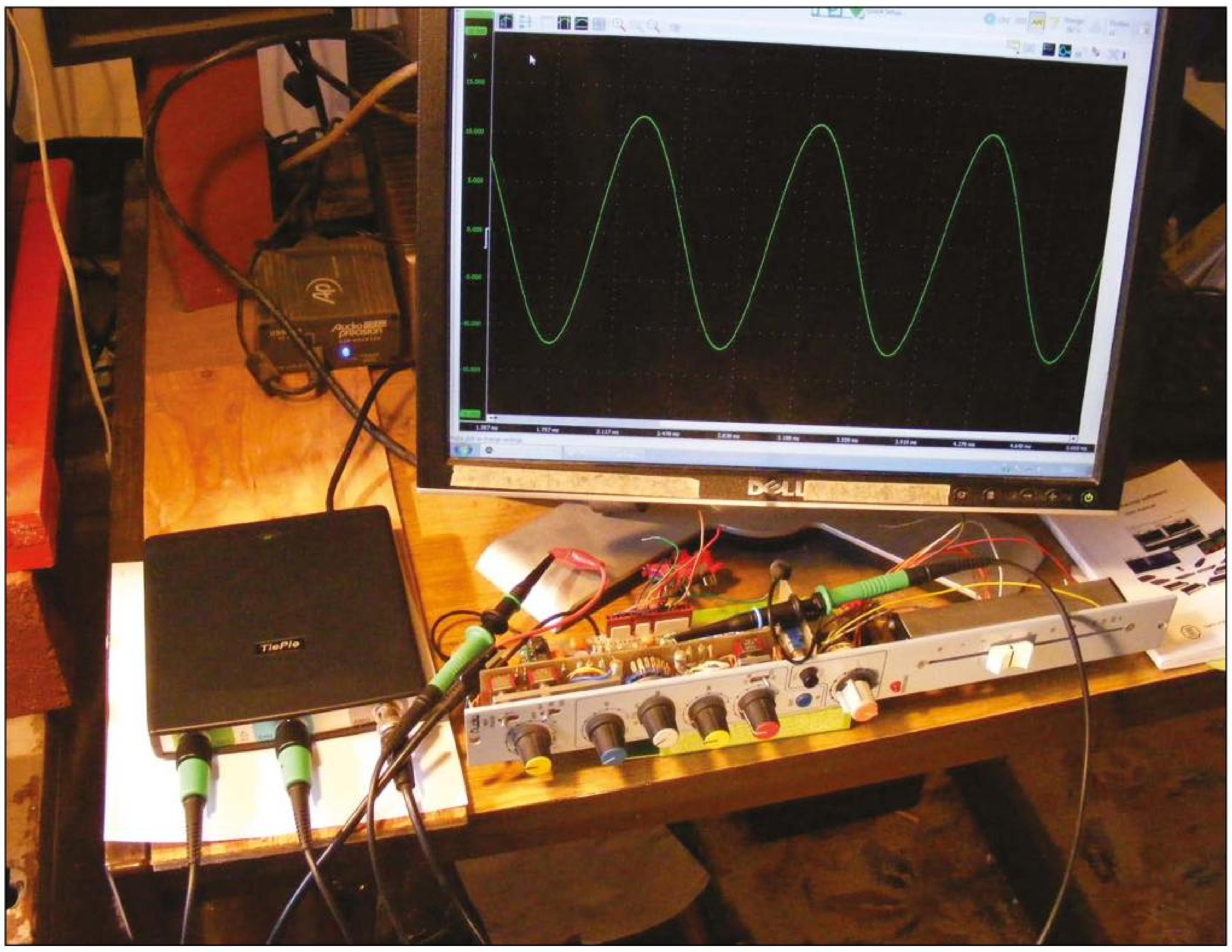


Fig.3. A typical messy test bench set-up showing the scope connected to a mixing desk channel.

Installation

I must confess that there was one other thing that had previously put me off taking the digital scope plunge – like all computer-based instruments, I was worried about tackling the inevitable fun and games around software installation and the learning curve of using instrumentation software. (Analogue scopes had become completely standardised by about 1970 and once learnt, they're 'like riding a bike' – not so digital scopes).

The unit is not 'plug-and-play'. I had to download the driver and measurement software (called *Multi Channel*) separately from the website. To do this, I had to look very carefully to get the correct ones. There is quite a choice, including legacy systems: Linux, MS-DOS, Windows and lots of different scope models. The unit was fine on Windows 7 and Windows 10 64-bit, but I had no luck with the 32-bit versions on my friend's old laptops. With the Windows 7 installation, I got a bit confused because the Multi Channel software had 'driver' in its name, making me forget to install the actual USB scope driver!

Operation

Once installed, I found the Multi Channel software straightforward and usable – even for an 'analogue' person. On a Windows 7 Hush PC desktop with 16GB RAM and an SSD, the scope was very fast with the lowest latency (delay between input change and display change time) I've experienced. This makes it great for trimming and peaking analogue circuits. Of course, there are so many variables that affects acquisition time that it's possible I did not have every setting the same when doing comparisons. Latency is one of the things I hate about digital instrumentation. A long delay between doing something and then the display changing has always made me feel it's a simulation and breaks the hand-display-brain feedback loop essential for experimental work. Here, the Handyscope behaved admirably.

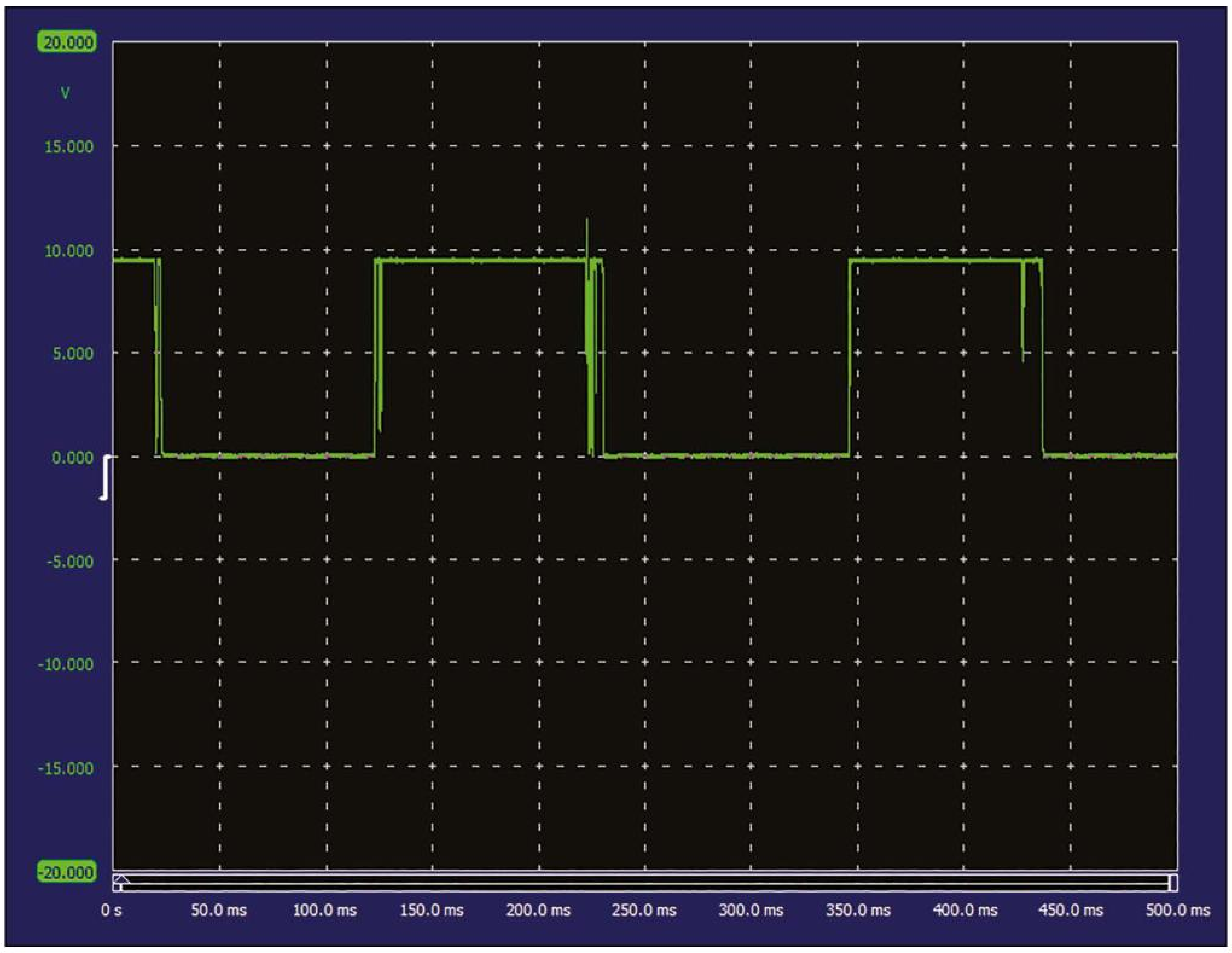


Fig.4. The storage facility enables transient events to be seen, such as this switch bounce.

Earthing

There is always the possibility with computer-connected equipment that noise from the computer's power supply contaminates some of the measurements. This could be a problem with some old mains-powered desktops, but a battery-powered laptop avoids this problem. I had no problems, but out of interest, I did try a **hifimediy.com** USB isolator between the Handyscope and the computer. This created more problems than it solved, causing the software to crash when it ran out of speed with sample rates of 500kSa or over. In this case, it was clearly a case of follow the instructions and keep things simple.

Results

I've only included a few static screen shots, since the real beauty of audio scope measurements is in the dynamics. There's a button in the file menu in the upper Windows tool bar that says 'save image' which is how these screen shots were obtained. I accidentally hid/closed the tool bar at one point. Only a hard power-down of scope and restarting the computer restored it. The system otherwise saves your settings and your mistakes, so I occasionally had to click out/in the TiePie icon and start again. If you are a software savant these things are no problem. If not, it can be confusing – but as with all software, 'practice makes perfect', and I freely admit I'm a beginner with Multi Channel.

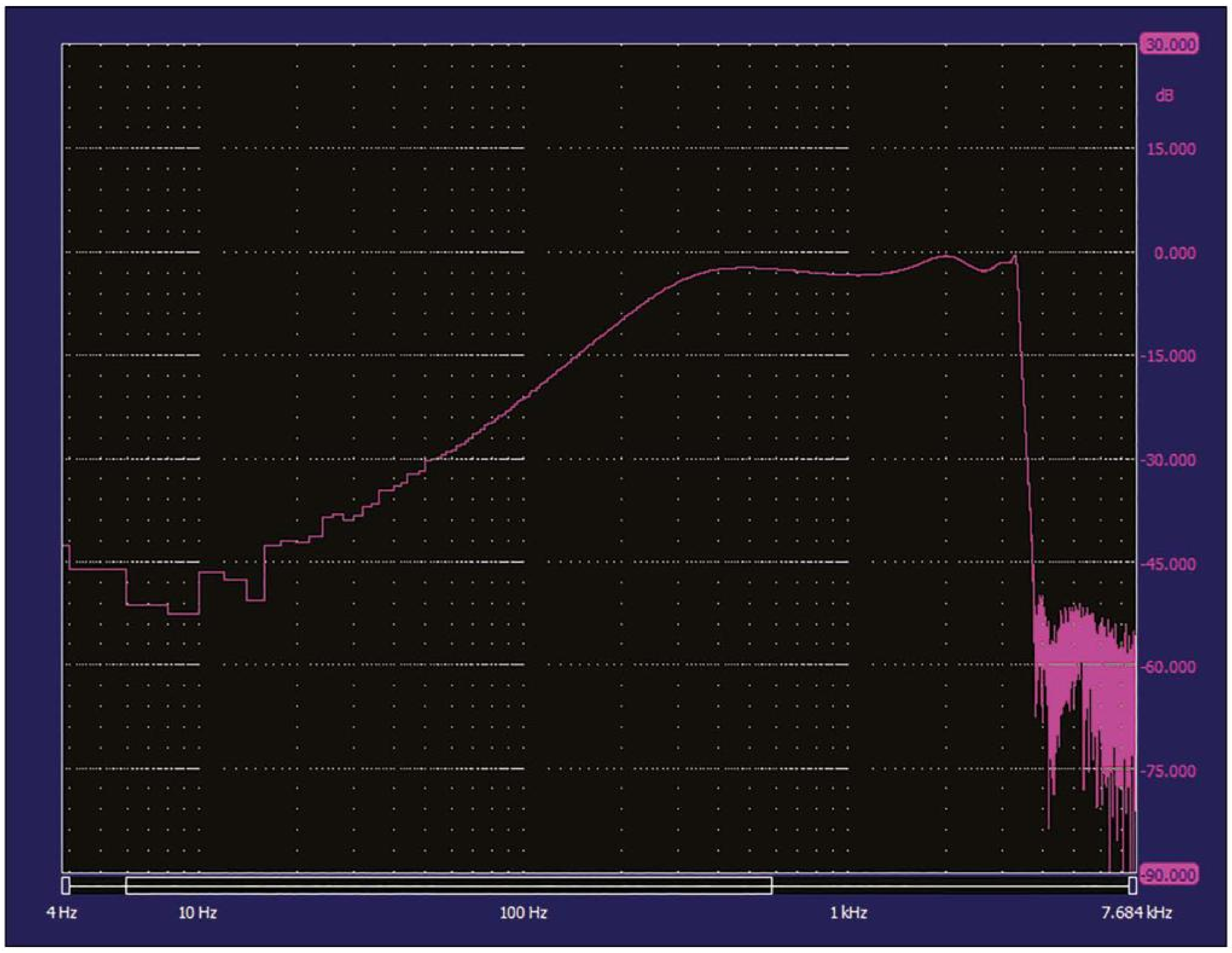


Fig.5. Frequency response plot of a speech band-pass filter. This was done by selecting a sample rate of 50kHz and a recording length of 16.38k samples.

Storage scope

Digital scopes can capture transient events by virtue of their storage capability. It can be very difficult to see something like a humble switch bounce on an analogue standard scope. Fig.4 shows a horrific switch guaranteed to send any control system into apoplexy. (You'd select floor 2 on the lift and end up at 29!). Clearly the HS5 caught the multiple bounces with ease.

Metering

The scope has a very useful multimeter facility. I found the massive virtual analogue scale very good for teaching with a big HDTV screen. There is a measurement icon on the scope that will give you everything you need, such as frequency, V_{rms} and $V_{pk\text{-}pk}$. The days when students had to read graticules are gone. Deskilling perhaps, but definitely delivering greater accuracy.

Frequency response

I managed to capture some excellent audio results, such as a frequency response plot with the correct log axes or dB level vs log frequency. The plot shown in Fig.5 is for a speech processor filter which I use for 'NASA moon-landing vocals' in music. Note how the response curve is 'blocky' on the low end, this is because I did it quickly. If I had swept the response more slowly there would have been more cycles in the low frequencies for the system to acquire, improving the accuracy. There are always such speed/accuracy trade-offs in measurement. Obtaining such response curves generally needs expensive equipment, such as an Audio Precision analyser, so I was pleasantly surprised that the HS5 did such a good job. Normally, audio response curves only go down to 20Hz, but I was pleased to see I could set this minimum to a much lower value (down to 1Hz) enabling me to check for coupling capacitor anomalies.

Spectrum analysis

The Handyscope performed spectrum analysis particularly well, much better than other bits of software I've used. My bench-top signal generator has developed a slightly lop-sided waveform. The fast-Fourier-transform-derived (FFT) spectrum analysis plot in Fig.6 shows there are unwanted even harmonics in the triangle waveform. It's possible to allow the FFT algorithm to optimise its resolution by setting the sampling rate and the record length separately to find particular frequencies in a noisy signal. By raising the Multi Channel integration time, the low-frequency resolution increases – an excellent way of looking at harmonics buried in noise.

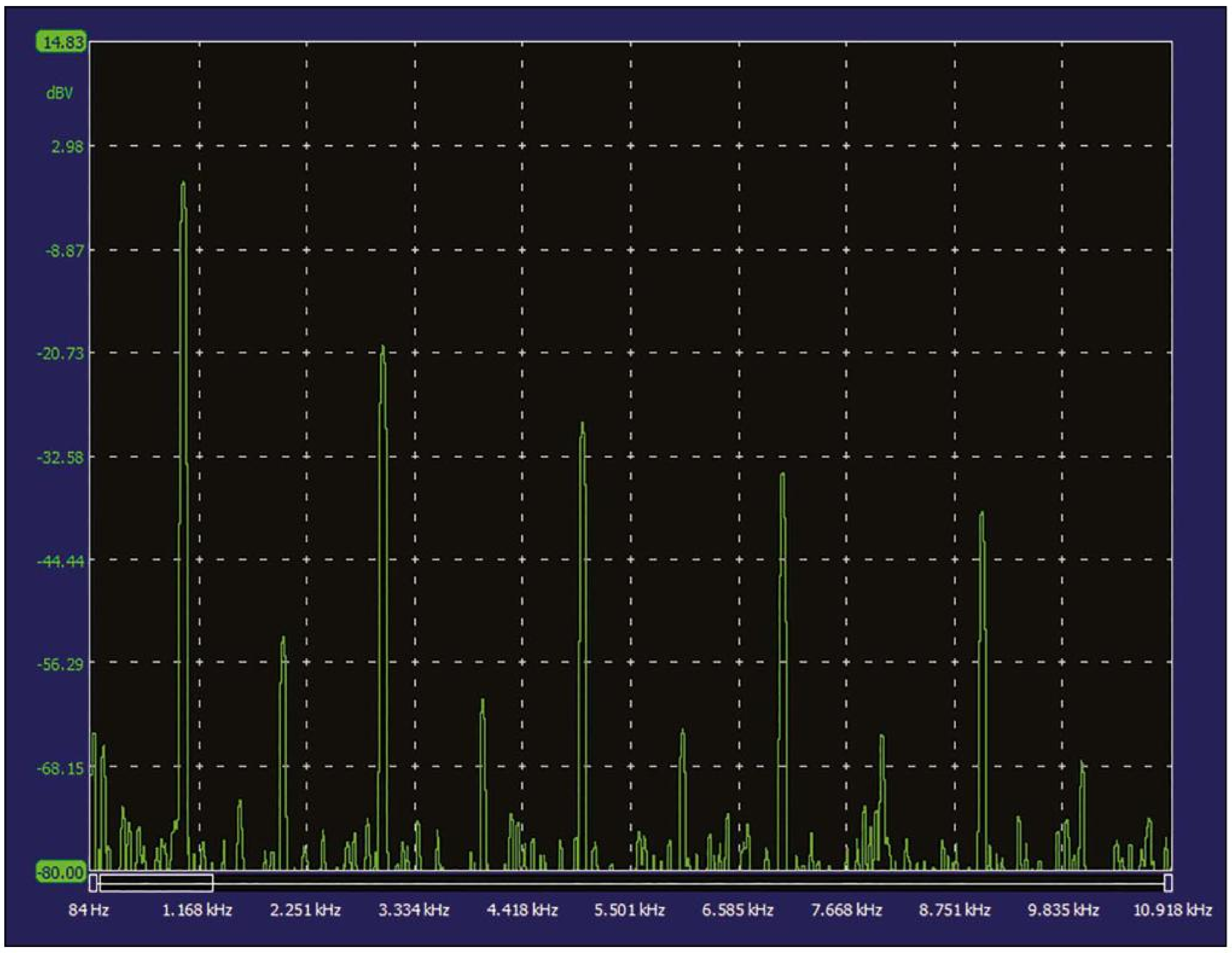


Fig.6. Spectral response of a bad signal generator. This was a distorted 1kHz triangle waveform, which is supposed to have only odd harmonics. (Excuse the numbering on the frequency axis. It is possible to slide the cursor along to get whole numbers as in Fig.7.)

Distortion

While playing with the Multi Channel software I discovered the unit could perform a percentage total harmonic distortion (THD) measurement by adding up all the harmonics in the spectrum analysis plot and comparing these to the fundamental. This takes quite a bit of maths to do by hand. In the true software-designer-fashion hated by hardware knob-twiddlers like me, it was difficult to find this function. It's a right-click drop-down menu, only available if you move a vertical marker cursor onto the fundamental spike on the spectrum analysis plot. Then you have to click on the abstract icon called 'value window' and finally, there's a little THD symbol you can click. Again, standalone THD measuring devices are expensive, so this function also justifies the Handyscope's cost. If you can't remember how to access this function then fortunately fallible human memory has been anticipated by allowing settings to be stored (along with images). Fig.7 shows the THD of a very simple oscillator based on an RA53 thermistor designed by John Linsley Hood. I always thought it sounded pure. Now I know it is, with just 0.016% THD.

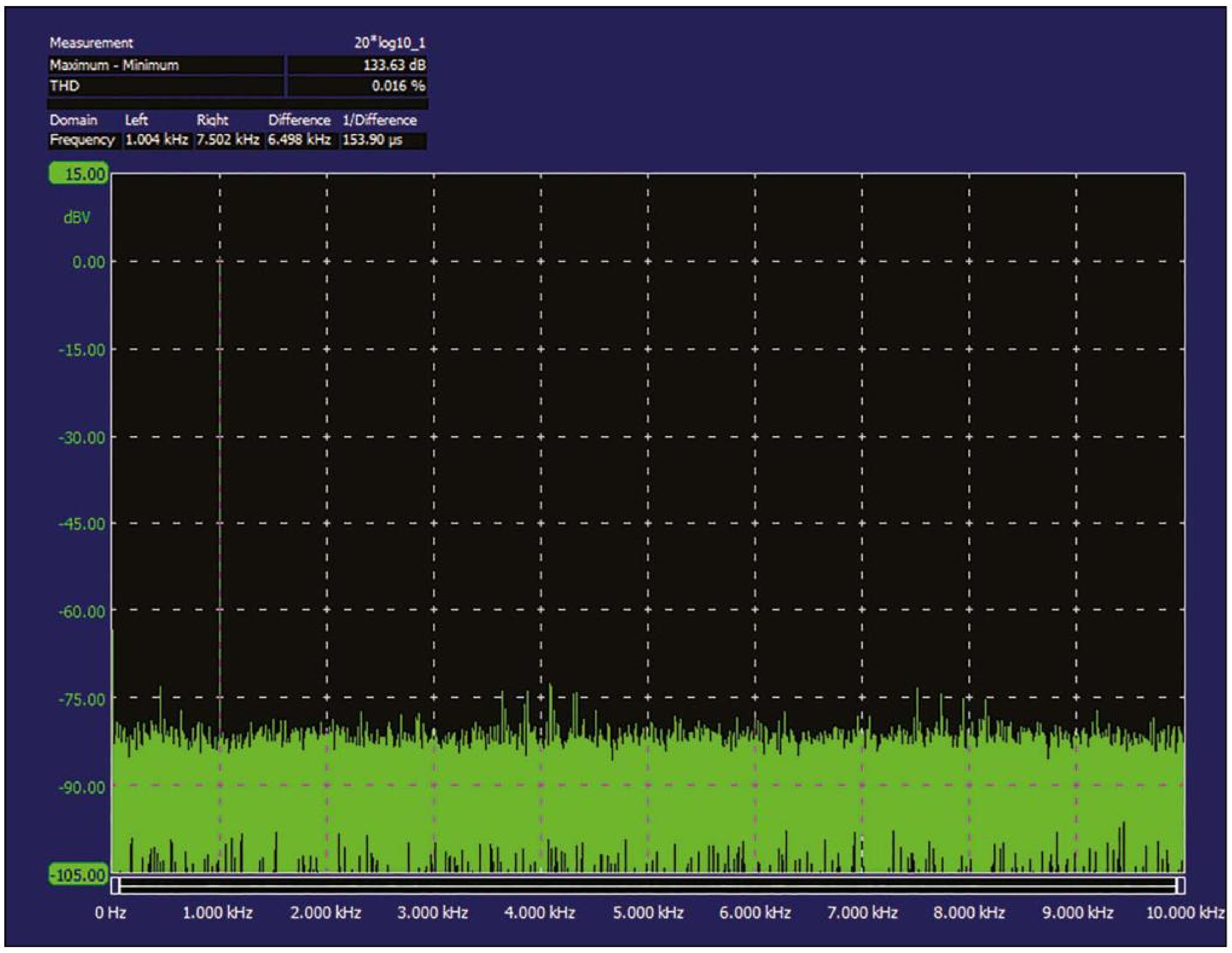
It's even possible to average out multiple FFT readings to further reduce noise, as astronomers do to analyse distant celestial bodies, a unique facility. Getting to this function is via the object tree and involves a lot of clicking. I averaged 8 FFTs together for the RA53 oscillator, which enabled the harmonics to be seen more clearly, as shown in Fig.8. It took about 10 minutes to compute.

Waveform generator

One aspect of the Handyscope I particularly liked was the built-in waveform generator. It has its own output BNC connector and can be set using a little window to output almost any waveform – hence its name, 'Arbitrary Waveform Generator' (AWG). It can output pulses, tone bursts, asymmetrical sinewaves… up to 40MHz for the 540 model and 5MHz for the 055. It is accessed by a funny-looking icon that I guess is supposed to represent the front panel of a bench generator. There is a reassuring relay click from the box when the output is switched on. (The AWG defaults to off, useful for preventing hearing damage!) I did some basic tests and found it could deliver a maximum output of 24V$_{\text{pk-pk}}$ sinewave at 1kHz, the standard audio test frequency. The output impedance is 50Ω. When loaded with a 51Ω resistor the output dropped to 12V$_{\text{pk-pk}}$, as expected, and there was no clipping. This equates to about 720mW, which may tax some low-power USB sources, which explains why TiePie recommend using the external power supply when the AWG is switched on. I measured the distortion using the built-in spectrum analyser and found it to be 0.023%, which is pretty good.

Petrol heads

I noticed a whole suite of software measuring tools for automotive applications, so if you want to set your cam belts and fuel injectors, you will love it. It seems this is one of TiePie's main markets.



Measurement	20*log10_1
Maximum - Minimum	133.63 dB
THD	0.016 %

Domain	Left	Right	Difference	1/Difference
Frequency	1.004 kHz	7.502 kHz	6.498 kHz	153.90 µs

Fig.7. Spectral response of a clean RA53 1kHz sinewave oscillator. Notice how the THD+noise figure is given as well (box, top-left corner).

Further information

iTP (innovative Technology Projects Ltd)
https://www.itp101.com
+44 (0)1480 700158
info@itp101.com

Summary

Let's get the question of cost out the way first. The HS5 isn't cheap, priced at £895 for the basic model HS5-055, rising to £1331 for the HS5-540 XM (which has ten-times more acquisition memory and a 40MHz sampling rate). So, it's not a beginner's unit. It's aimed at experienced hobbyists (and of course professional users). The above prices are excluding VAT and shipping, which can vary. Luckily, the cheaper HS5 5MHz sampling model offers more than enough facilities for audio work. (There's a very similar 16-bit Pico scope, the 4262, which costs £1025). One crucial point when you weigh up the unit's price and value-for-money – do consider what this understated 'little black box' can do. It's actually relatively inexpensive because it replaces a whole slew of separate pieces of test gear. Remember – it's not just a scope, but also a meter, signal analyser, plotter, function generator and more.

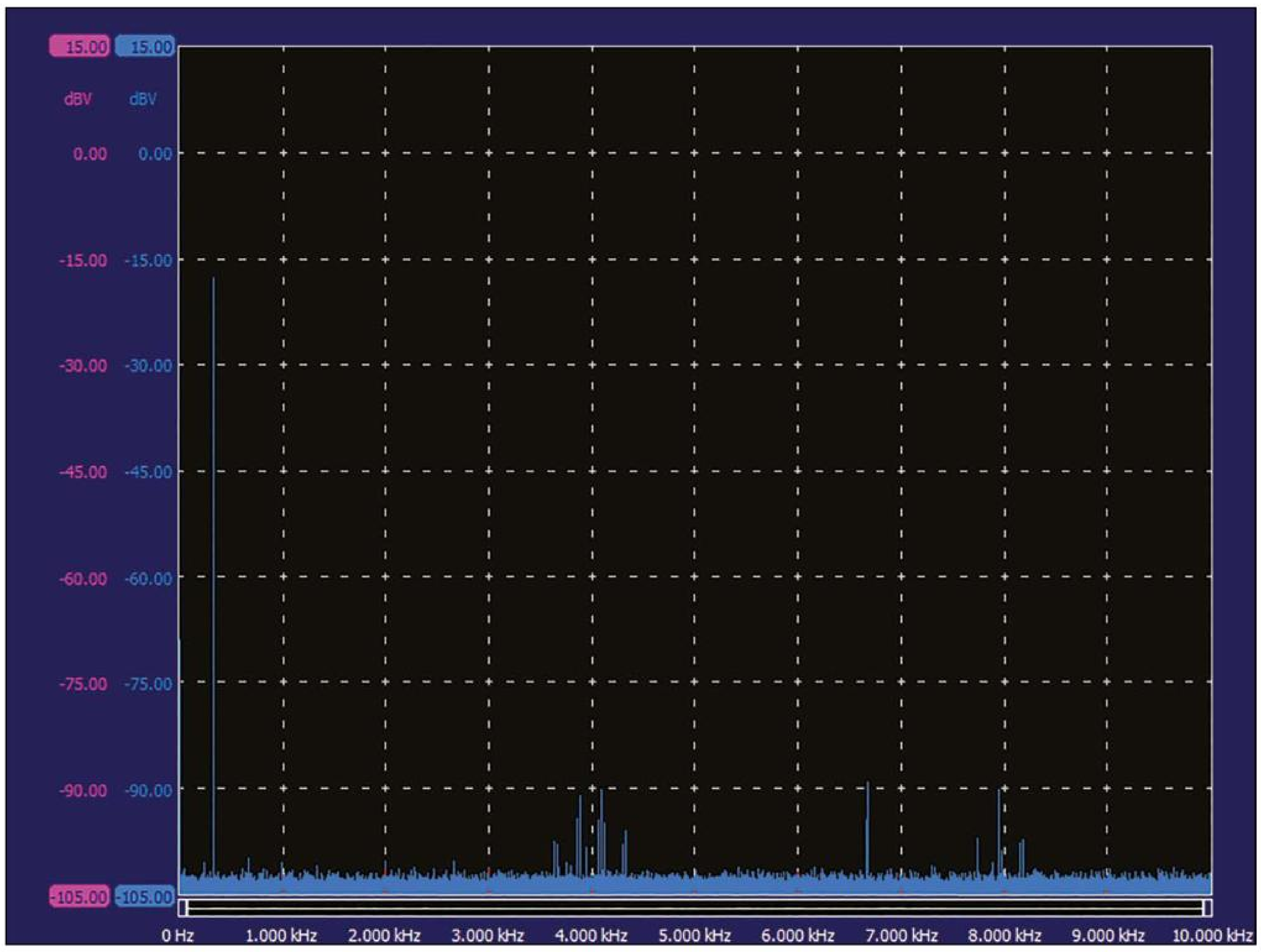


Fig.8. Averaged FFT spectral response of RA53 oscillator set to 330Hz . Note how the noise floor has been reduced relative to the harmonic spikes.

The HS5 works beautifully on the bench and is the ideal 'rucksack scope' in conjunction with a compatible laptop – so much easier to carry on the train. No more struggling in a car stacked with 20kg of CRO, bench signal generator and plotter. For me, it was the specialised measurement functions that made it really worthwhile. I want to buy it, but right now it's a case of 'heating or scoping', so I may have to wait and hope for a warm spring!

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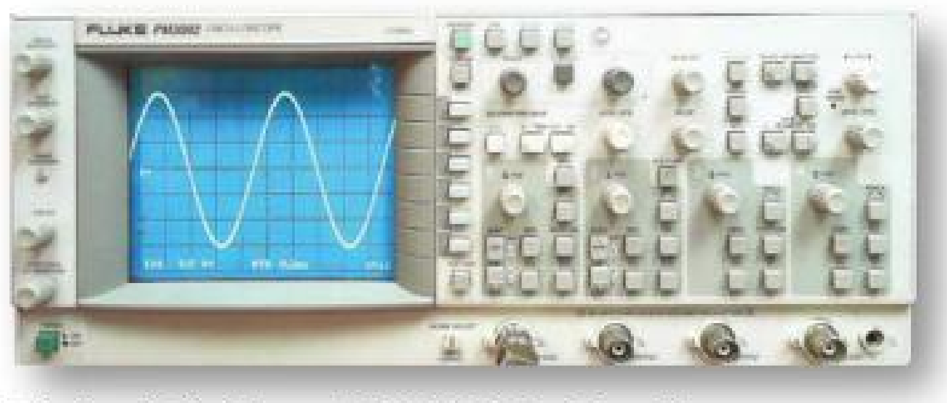

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HP8757D	Scaler Network Analyser	POA
HP3325A	Synthesised Function Generator	£195
HP3561A	Dynamic Signal Analyser	£650
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Marconi 2030	Synthesised Signal Generator 10kHz – 1.35GHz	£750
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Marconi 2945/A/B	Communications Test Set Various Options	POA
Marconi 2955	Radio Communications Test Set	£595
Marconi 2955A	Radio Communications Test Set	£725
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Marconi 6200	Microwave Test Set	£1,500
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Tektronix TDS3052B	Oscilloscope 500MHz 2.5GS/s	£1,250
Tektronix TDS3032	Oscilloscope 300MHz 2.5GS/s	£995
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Audio Precision	SYS2712 Audio Analyser – in original box	POA
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Druck DPI 515	Pressure Calibrator/Controller	£400
Datron 1081	Autocal Standards Multimeter	POA
ENI 325LA	RF Power Amplifier 250kHz – 150MHz 25W 50dB	POA
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Make it with Micromite

Phil Boyce – hands on with the mighty PIC-powered, BASIC microcontroller Phil B

Part 45: Updating the PicoMite firmware

During development of the *PicoMite Fingerprint Reader* (our current *Make it with Micromite* project), a new version of the PicoMite firmware was released. Normally, we would simply make you aware that a new version of MMBASIC was available, allowing you to update your PicoMite(s) as and when convenient. However, in this latest release, there are some fundamental changes to the way the PicoMite behaves (as well as the usual performance improvements, and some new commands).

One noticeable change concerns the storage (and subsequent access) of program files, data files, image files and sound files. Traditionally, if required, files would be stored on an attached SD card; however, this new firmware allows files to be also stored in the PicoMite's own internal Flash memory. This new feature is something that we should be able to benefit from in the *Fingerprint Reader*, and hence this firmware update should be regarded as an essential requirement for your PicoMite(s).

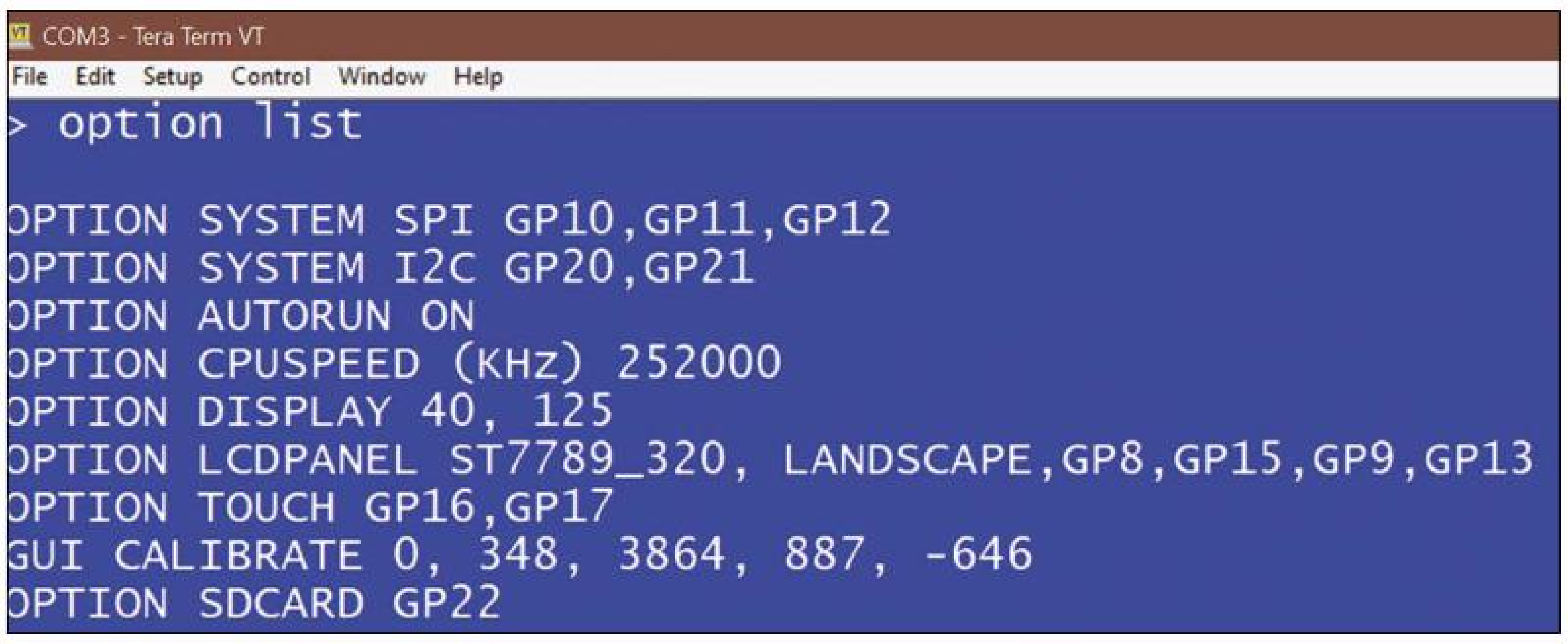
Therefore, we will begin this month with a quick explanation of how to upgrade your PicoMite(s) with this latest release of MMBASIC, and then we will discuss the hardware required to build the *Fingerprint Reader*. We will explain how to configure the required `OPTION`s to ensure that the new firmware is able to access the SD card; and we will finish by loading a simple test program to ensure that everything is connected correctly. Let's begin by downloading the required files.

PicoMite v5.07.06

Just two files need to be downloaded: the firmware file (**PicoMiteV5.07.06.uf2**), and the *User Manual* (**PicoMite_User_Manual.pdf**). These are both available for free download by visiting: **https://geoffg.net/picomite.html**

Simply scroll down to the 'Downloads' section (located towards the bottom of the page) and click on the DOWNLOAD button which is next to the description: *PicoMite firmware V5.07.06 (includes the above manual)*. This will download a zipped folder from which you can unzip (extract) the two required files. Alternatively, you can download them both from the March 2023 page of the *PE* website: **https://bit.ly/pe-downloads**

Fig.1. To see what `OPTIONS` have been set, use the `OPTION LIST` command.



```
> option list

OPTION SYSTEM SPI GP10,GP11,GP12
OPTION SYSTEM I2C GP20,GP21
OPTION AUTORUN ON
OPTION CPUSPEED (KHz) 252000
OPTION DISPLAY 40, 125
OPTION LCDPANEL ST7789_320, LANDSCAPE,GP8,GP15,GP9,GP13
OPTION TOUCH GP16,GP17
GUI CALIBRATE 0, 348, 3864, 887, -646
OPTION SDCARD GP22
```

Once you have these two files, store them in a convenient folder on your computer. I tend to leave the **.uf2** file in the Downloads folder, and put the *User Manual* in the Documents folder.

Uploading the firmware

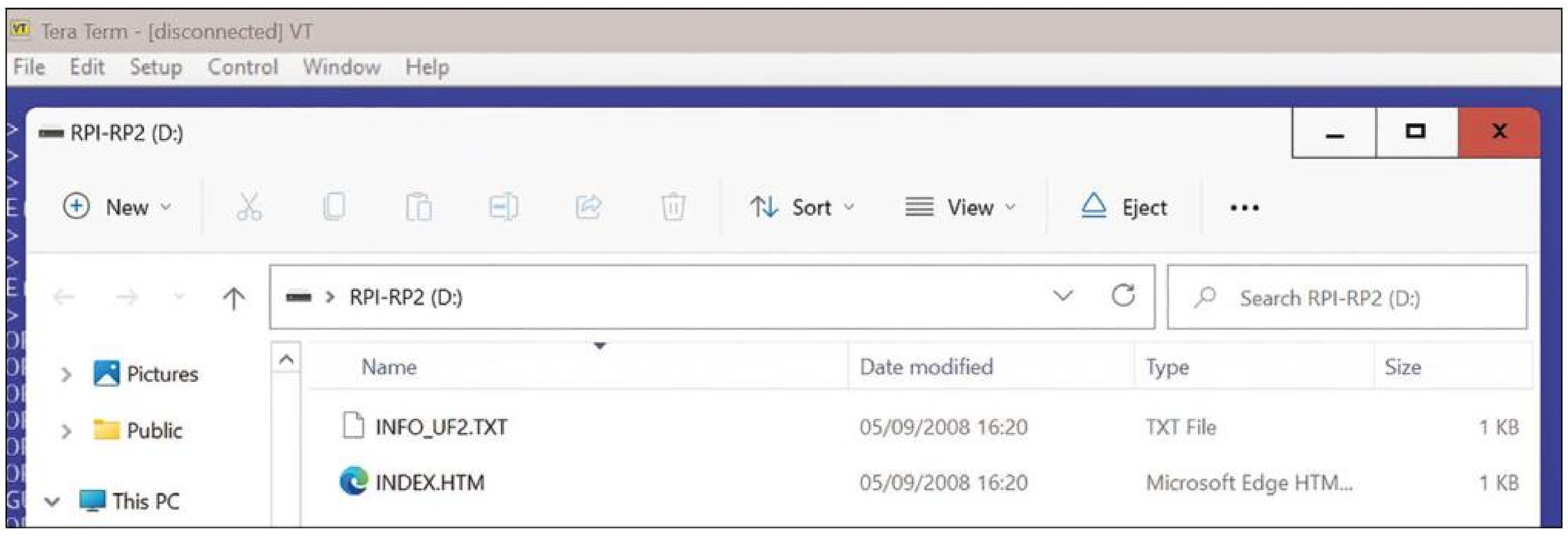
This process was covered in *MIWM Part 35* (*PE*, April 2022); however, since it's a quick-and-easy process, we will cover the steps again here. Note that it should take you less than a minute to complete the upload. However, if you're upgrading from a previous version of MMBASIC, then before you begin, there are two points to consider.

First, if you are currently working on a project and you simply want to upgrade to this latest version of MMBASIC, then ensure that you make a note of any `OPTION`s that you currently have set. This is because this firmware upgrade will wipe out all existing `OPTION`s – you have been warned! The best way to do this is, at the command prompt, type `OPTION LIST` and then simply take a screen grab (or photo) of what is displayed. (See Fig.1 for an example list of `OPTION`s).

Second, if you have any program code that you wish to keep, do back it up. To do this, at the command prompt, type `LIST ALL` and then (for TeraTerm) simply highlight the code displayed (to copy it onto the Windows clipboard), and then paste it into something like Notepad (or any other text editor). Next, save the Notepad file with a suitable filename into an appropriate folder.

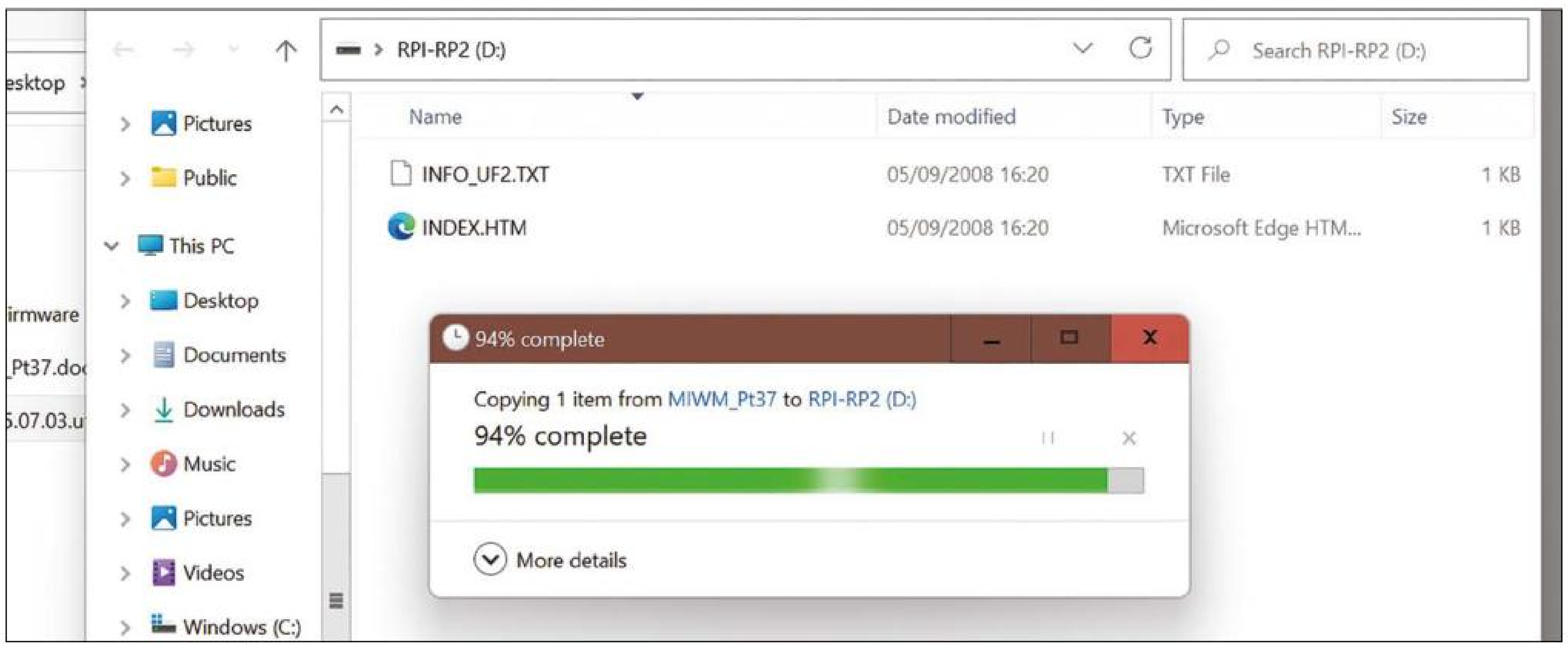
After saving any important information, you can now perform the firmware upload by following these four steps:

1. Begin by disconnecting the PicoMite from your computer (ie, remove power to the PicoMite).
2. Press the BOOTSEL button (on the PicoMite) and hold it down as you plug the PicoMite into the USB port. This will result in the Pico powering up into what is known as 'Bootloader Mode' – it will appear to the computer as an additional USB Flash drive. This is signified by a new 'Pico Drive' Window automatically displayed on your computer (see Fig.2). NOTE: Do not delete either of the two files currently in the 'Pico Drive'.
3. Paste (or drag / drop) the downloaded firmware file (**PicoMiteV5.07.06.uf2**) into the 'Pico Drive'. This will immediately start the upload process, and a progress bar will appear briefly (see Fig.3)
4. Once the upload is finished, remove the PicoMite, then re-insert it and start up your preferred Terminal program. You should now see the firmware has been upgraded to version v5.07.06, as indicated in the PicoMite's power-up 'Welcome message' (see Fig.4)


Tera Term - [disconnected] VT
File Edit Setup Control Window Help
RPI-RP2 (D:)
New
Sort
View
Eject
RPI-RP2 (D:)
Search RPI-RP2 (D:)
Pictures
Public
This PC

Name	Date modified	Type	Size
INFO_UF2.TXT	05/09/2008 16:20	TXT File	1 KB
INDEX.HTM	05/09/2008 16:20	Microsoft Edge HTM...	1 KB

Fig.2. If the BOOTSEL button is pressed while connecting the Pico to a computer, this 'Pico Drive' window will automatically appear.


RPI-RP2 (D:)
Search RPI-RP2 (D:)
Pictures
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This PC
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Documents
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Videos
Windows (C:)
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Name	Date modified	Type	Size
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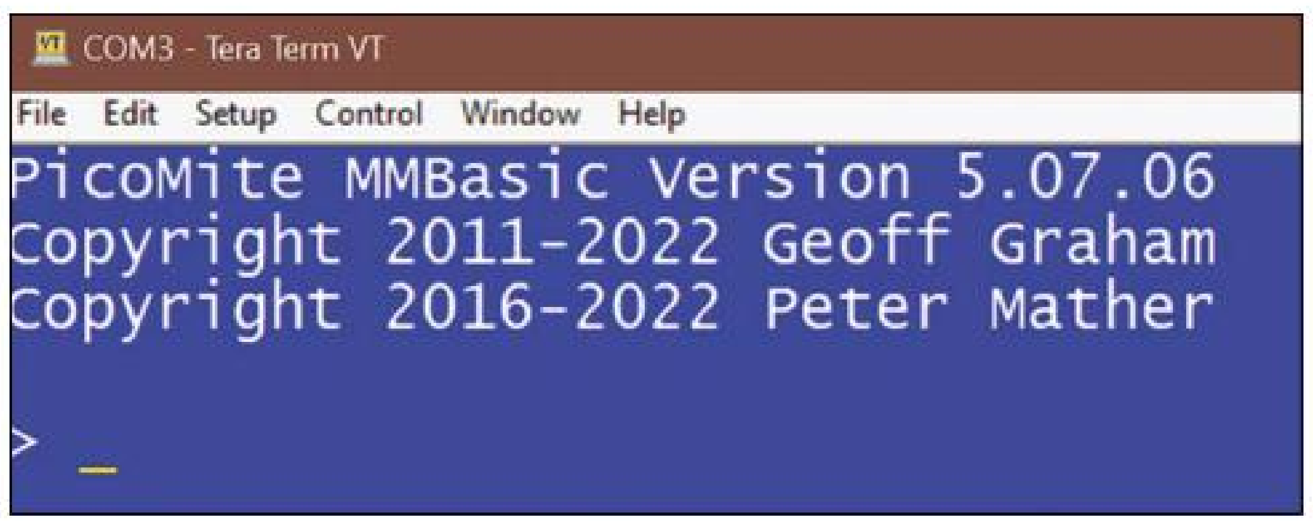
Copying 1 item from MIWM_Pt37 to RPI-RP2 (D:)

94% complete

Fig.3. When the .uf2 firmware file is moved into the Pico Drive, it will automatically be processed, during which time a progress bar is displayed.


COM3 - Tera Term VT
File Edit Setup Control Window Help

```
PicoMite MMBasic Version 5.07.06
Copyright 2011-2022 Geoff Graham
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> _
```
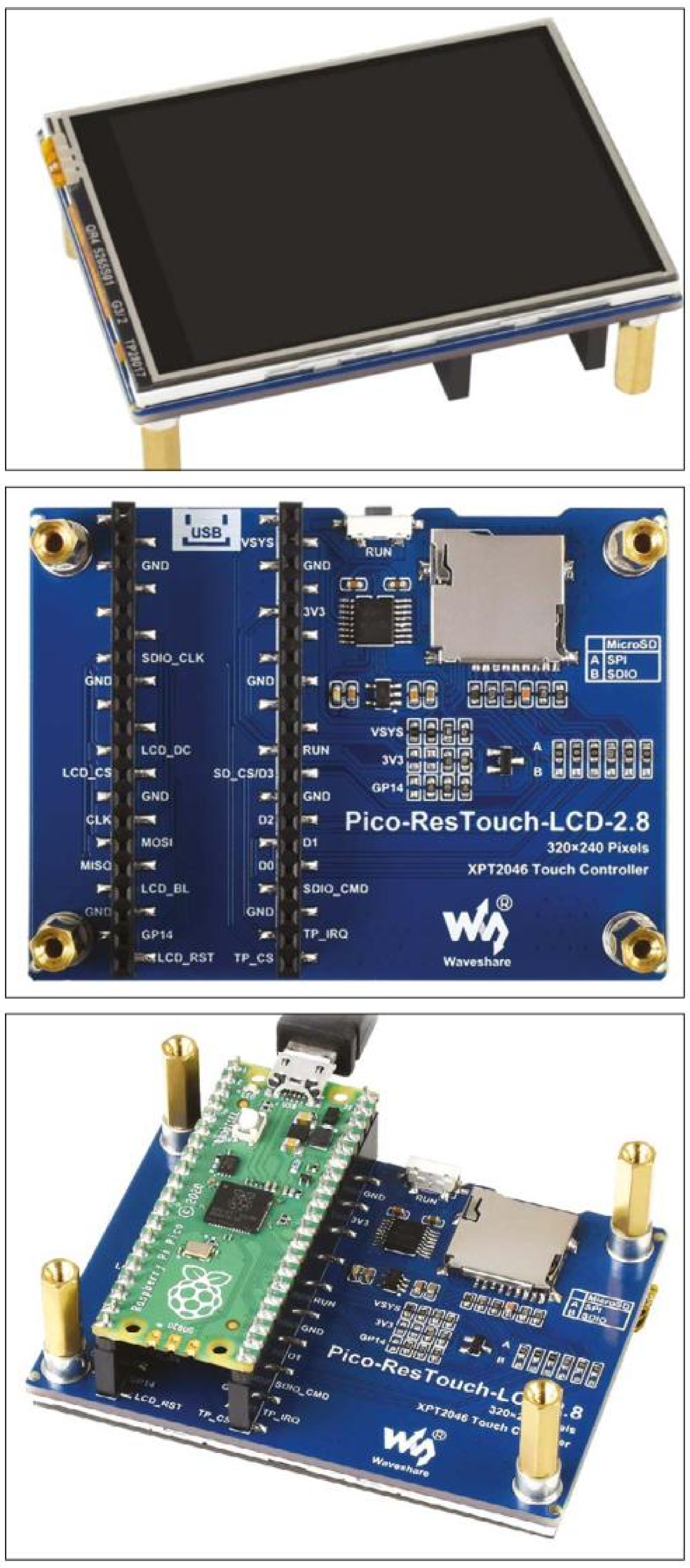

Fig.4. (left) Here, the PicoMite's welcome message (displayed at power-up) confirms that MMBASIC has been upgrade to version v5.07.06.


USB
VSYS
GND
3V3
RUN
SDIO_CLK
LCD_DC
LCD_CS
SD_CS/D3
MOSI
MISO
LCD_BL
SDIO_CMD
GP14
LCD_RST
TP_CS
TP_IRQ
MicroSD
A SPI
B SDIO
Pico-ResTouch-LCD-2.8
320×240 Pixels
XPT2046 Touch Controller
Waveshare

With the firmware upload complete, you can now proceed to set `OPTION`s as required. However, if the upgrade failed, then simply repeat the above four steps again. The most common issue is with step 2 if the BOOTSEL button isn't pressed at the time the PicoMite is powered up. If you don't see the 'Pico Drive' window appear shortly after you insert the PicoMite, then re-insert it with the button firmly pushed.

Fingerprint Reader hardware

The completed unit will comprise of the following four hardware modules:

1. PicoMite
2. 2.8-inch Touchscreen (Waveshare PicoRes Touch-LCD-2.8) – see Fig.5
3. Mini Real-Time Clock (RTC) module (Fig.6)
4. R503 Fingerprint module (Fig.7)

Fig.5. (Left and above) Front/rear views of the Waveshare 2.8-inch touchscreen module. Its three advantages are: low cost, based on IPS technology (better image than normal TFTs), and it has an onboard SD socket.

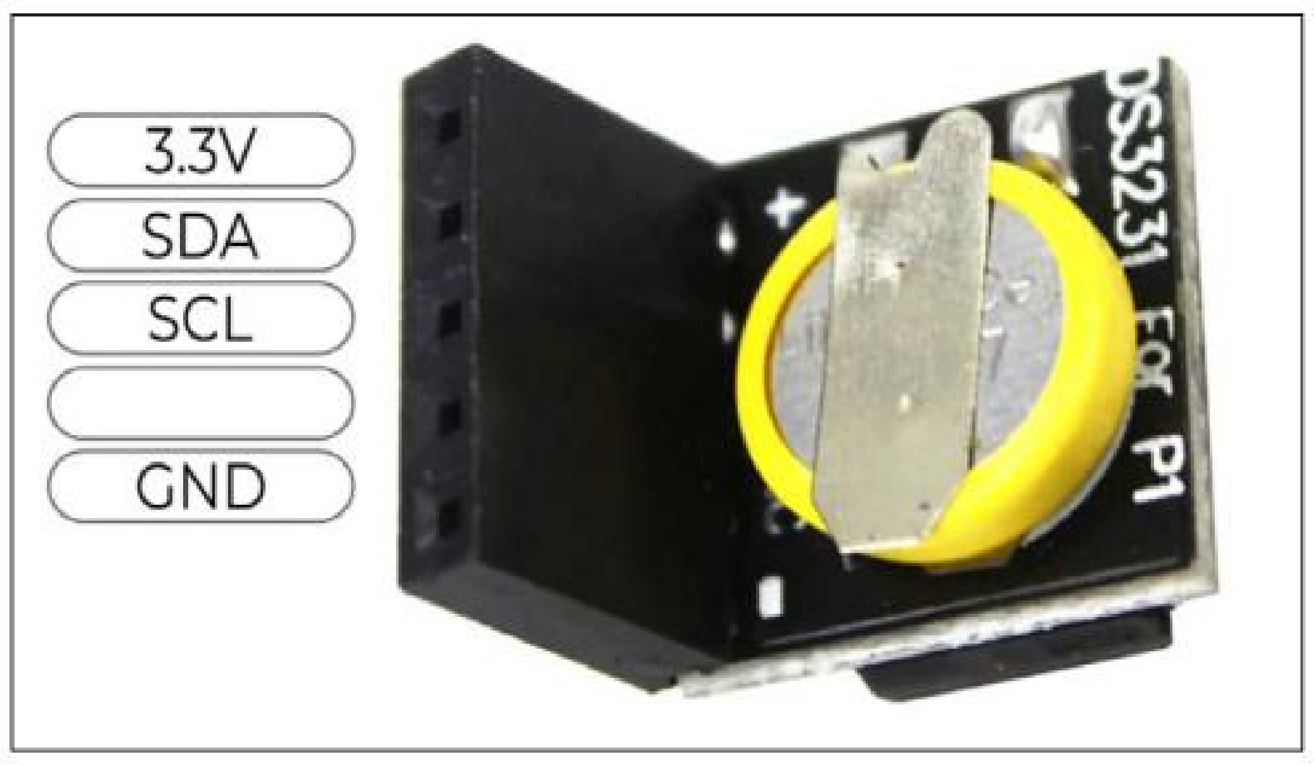

3.3V
SDA
SCL
GND
DS3231 For Pi

Fig.6. Our preferred RTC module. It will capture the time/date of a finger detection.

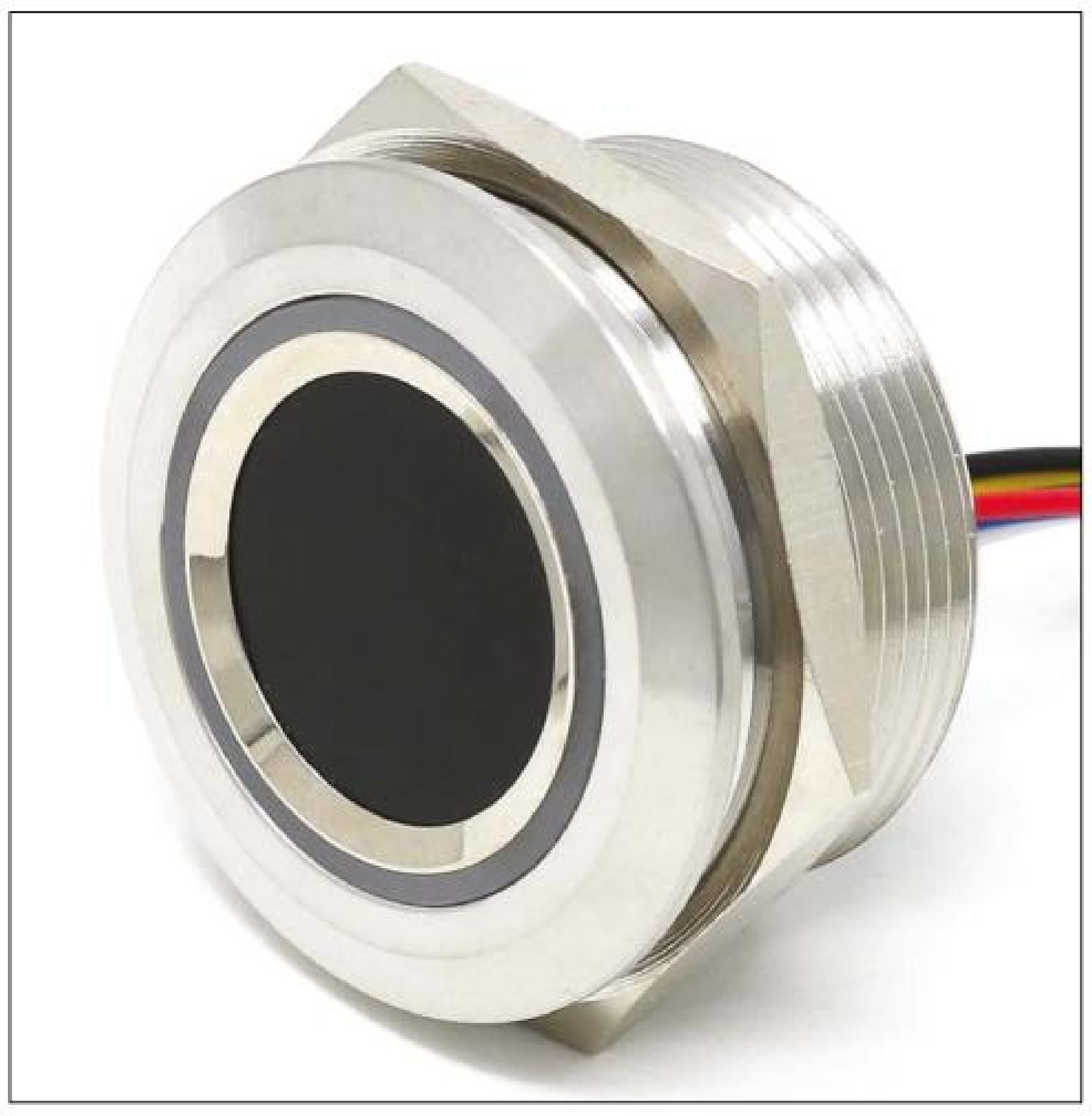


Fig.7. The R503 capacitive fingerprint sensor module. This was covered in detail in *Parts 1* (*PE*, December 2022) and *Parts 2* of the project (*PE*, February 2023).

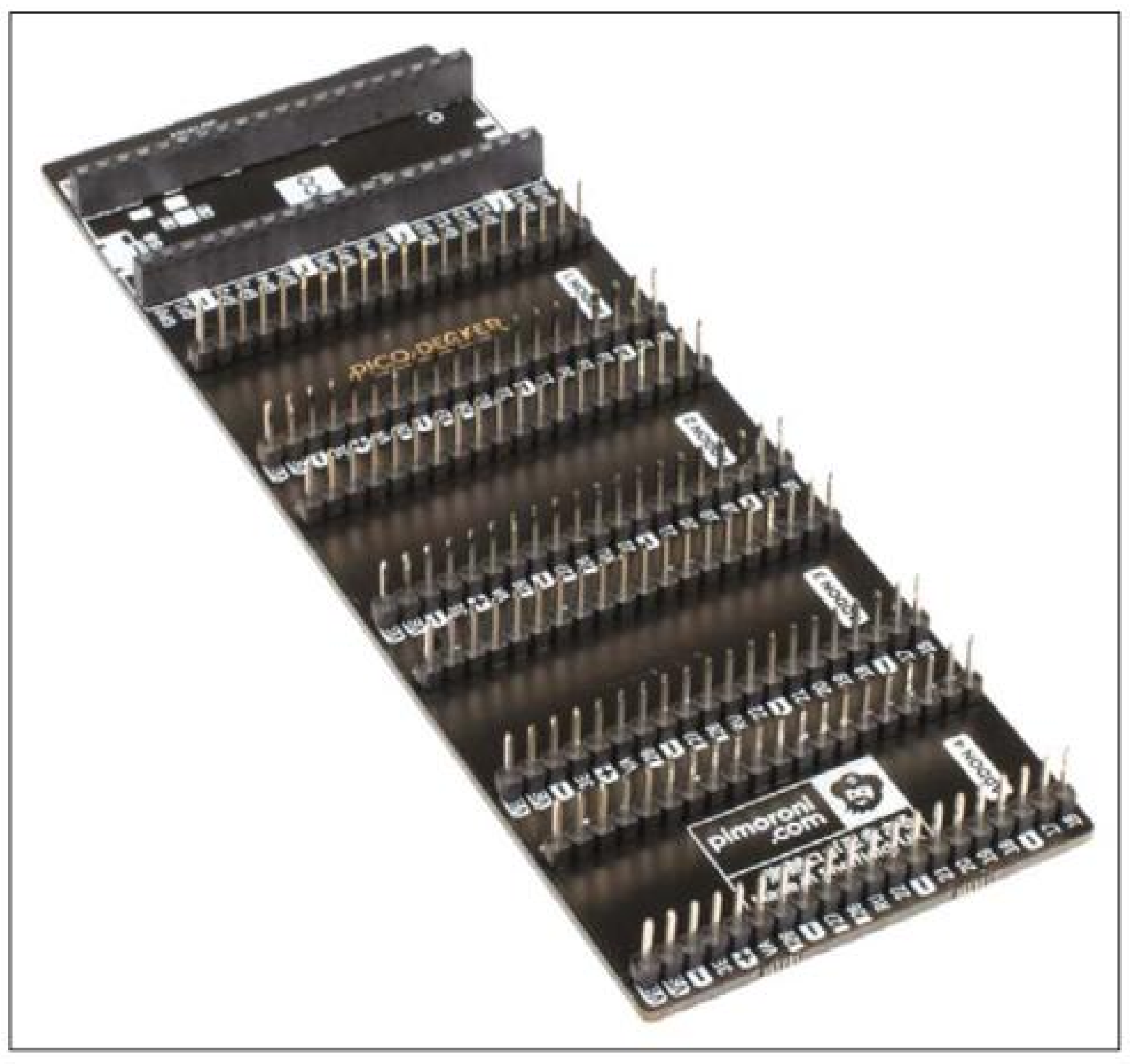

pimoroni.com

Fig.8. A Pico Expander module will simplify the connections to all the hardware elements.

To assist with development, a Pico expander module (see Fig.8) will also be useful to link everything together. We will use one to initially check that everything works as expected. Note that the Touchscreen module also comes with an onboard micro-SD socket which we will also be using in the *Fingerprint Reader*.

All connections are shown in Fig.9, and this will prove useful when it comes to connecting the RTC and R503 modules. It will also help clarify the parameters we'll be using when setting the required `OPTION`s.

Begin assembly by plugging the PicoMite into the Pico expander, taking care to align the micro-USB socket on the PicoMite with that shown on the Pico expander. (Note that the PicoMite should not be powered up at this stage.) Next, carefully insert the Waveshare module into a convenient place on the Pico expander, ensure you align the USB silkscreen on the display module with that on the Pico expander.

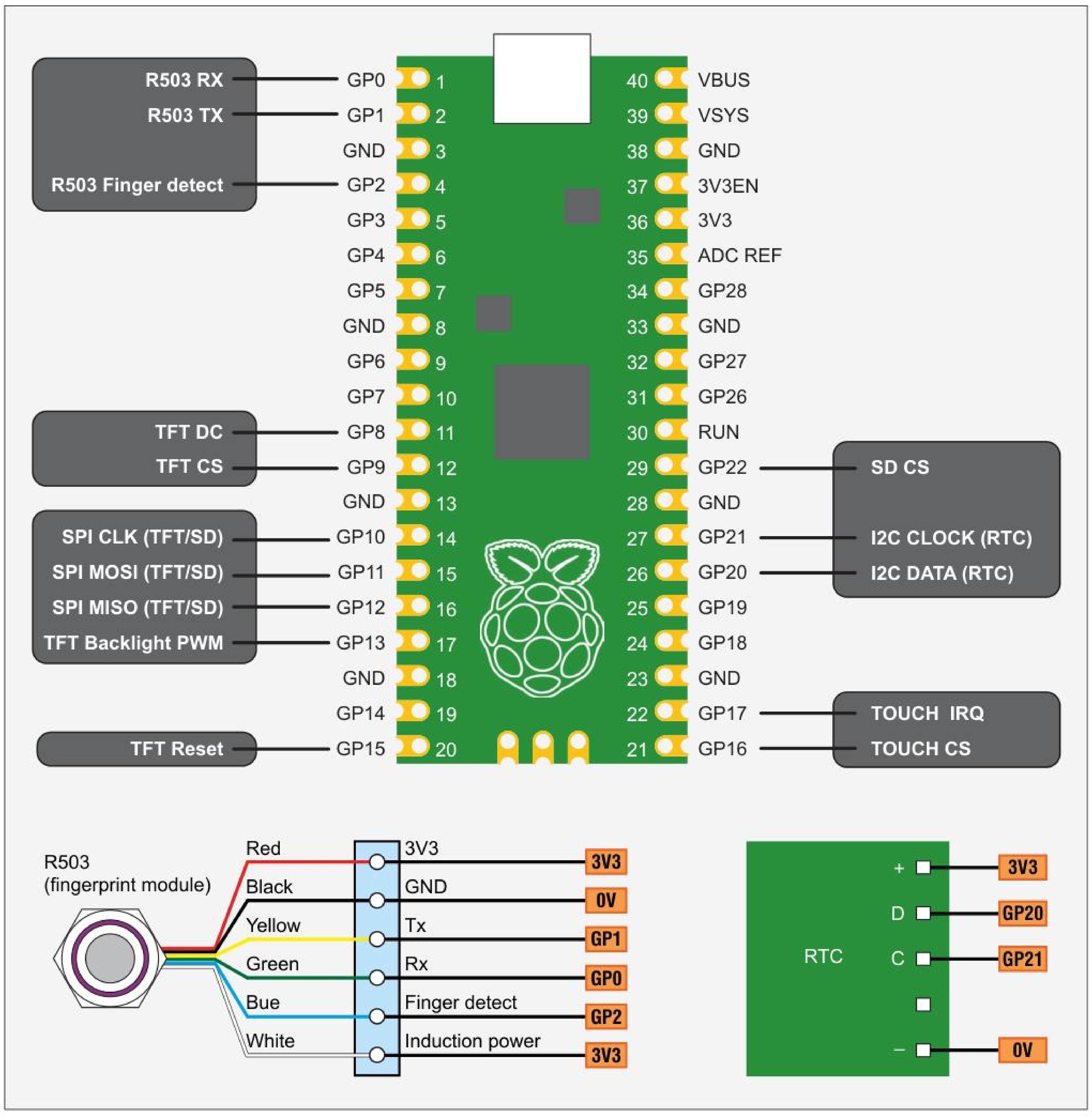

R503 RX
R503 TX
R503 Finger detect
TFT DC
TFT CS
SPI CLK (TFT/SD)
SPI MOSI (TFT/SD)
SPI MISO (TFT/SD)
TFT Backlight PWM
TFT Reset
GP0 1
GP1 2
GND 3
GP2 4
GP3 5
GP4 6
GP5 7
GND 8
GP6 9
GP7 10
GP8 11
GP9 12
GND 13
GP10 14
GP11 15
GP12 16
GP13 17
GND 18
GP14 19
GP15 20
40 VBUS
39 VSYS
38 GND
37 3V3EN
36 3V3
35 ADC REF
34 GP28
33 GND
32 GP27
31 GP26
30 RUN
29 GP22
28 GND
27 GP21
26 GP20
25 GP19
24 GP18
23 GND
22 GP17
21 GP16
SD CS
I2C CLOCK (RTC)
I2C DATA (RTC)
TOUCH IRQ
TOUCH CS
R503
(fingerprint module)
Red
Black
Yellow
Green
Bue
White
3V3
GND
Tx
Rx
Finger detect
Induction power
3V3
0V
GP1
GP0
GP2
3V3
RTC
+
D
C
–
3V3
GP20
GP21
0V

Fig.9. The *Fingerprint Reader* hardware is based around the PicoMite. All connections to it are summarised here.

The mini-RTC module can be connected by using four female-male DuPont leads. Pin D (I²C Data) on the RTC connects to GP20, and pin C (I²C Clock) connects to GP21. It is connected to 3.3V (and *not* 5V).

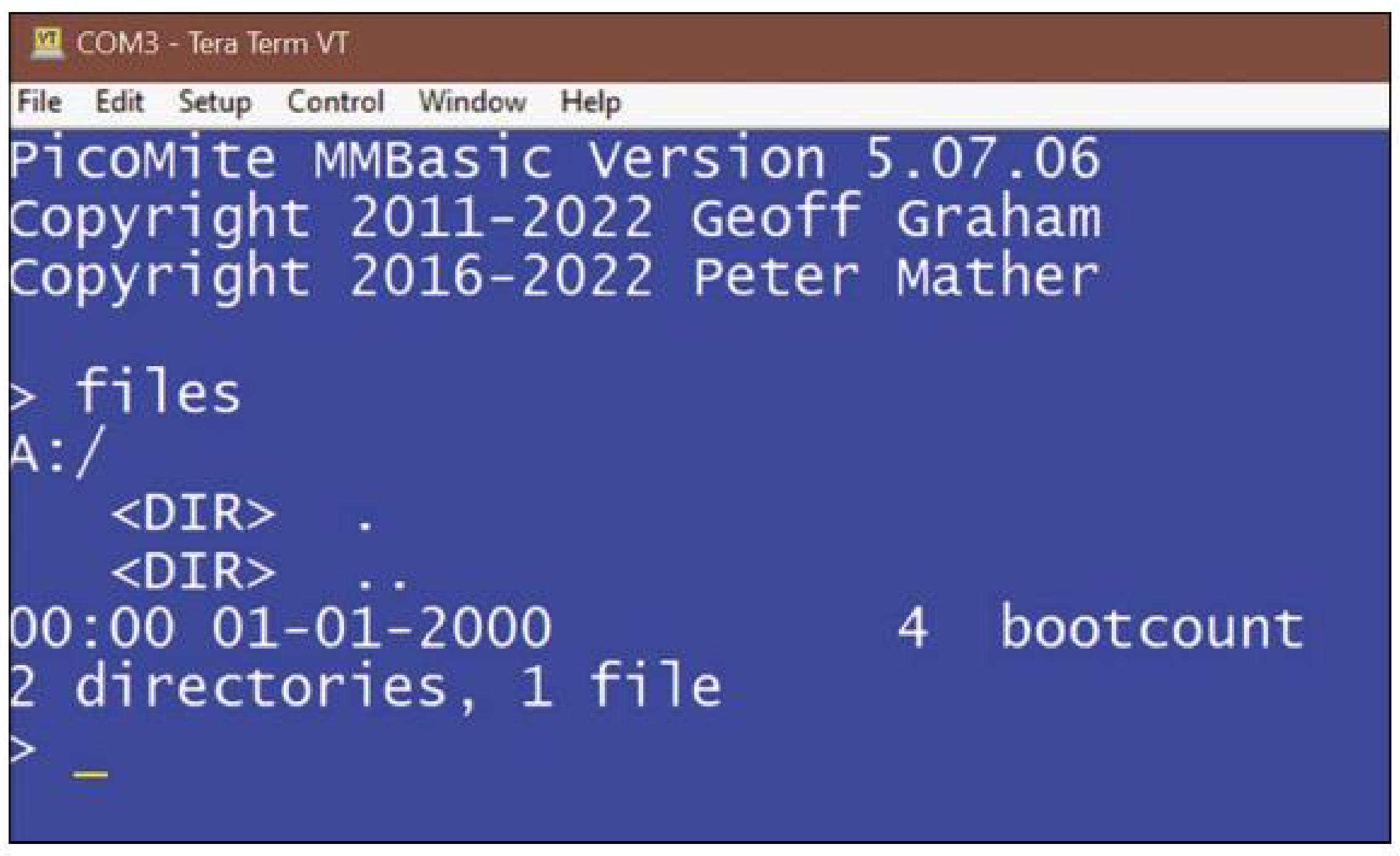
The R503 module is also connected to 3.3V, and to the PicoMite's COM1 pins on GP0 and GP1 (refer to Fig.9). The 'Finger Detect' output signal is connected to GP2.

With all the modules connected to each other, we can now proceed to configure the required `OPTION`s so that we can then test everything is connected correctly.

Configuring `OPTION`s

With the PicoMite connected to your computer, launch your preferred terminal program. At the command prompt, work through the following steps to configure each required `OPTION`:

- **`OPTION CPUSPEED 252000`** – this ensures that the PicoMite runs at 252MHz.
- **`OPTION SYSTEM I2C GP20,GP21`** – defines the I²C pins (SDA and SCL) that connect to the RTC module's D and C pins.
- **`OPTION SYSTEM SPI GP10,GP11,GP12`** – defines the SPI pins (CLK, MOSI, MISO) that connect to the TFT and the SD.
- **`OPTION LCDPANEL ST7789_320,L,GP8,GP15,GP9,GP13`** – defines the TFT pins (DC, RST, CS and Backlight) as used by the TFT module.
- **`GUI TEST LCDPANEL`** – draws multiple, colourful overlapping circles to confirm that the TFT is configured correctly. It will continue until you press a key on your terminal application. If nothing appears, it is likely that a parameter in `OPTION LCDPANEL` is incorrect (in which case, enter `OPTION LCDPANEL DISABLE` and carefully re-key the above step with the correct parameters).
- **`OPTION TOUCH GP16,GP17`** – defines the touch panel's CS and IRQ pins.
- **`GUI CALIBRATE`** – follow the onscreen instructions to calibrate the touchscreen (touch the four crosshairs in turn).
- **`GUI TEST TOUCH`** – this should draw a dot at the exact point that you touch the screen. Use a plastic stylus for this process so that you can confirm the accuracy of calibration. If the dot is not accurately placed, press any key to exit the test, and repeat the `GUI CALIBRATE` command.
- **`OPTION SDCARD GP22`** – defines the pin that connects to the SD card's CS pin


COM3 - Tera Term VT
File Edit Setup Control Window Help

```
PicoMite MMBasic Version 5.07.06
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> files
A:/
   <DIR>  .
   <DIR>  ..
00:00 01-01-2000         4  bootcount
2 directories, 1 file
> _
```
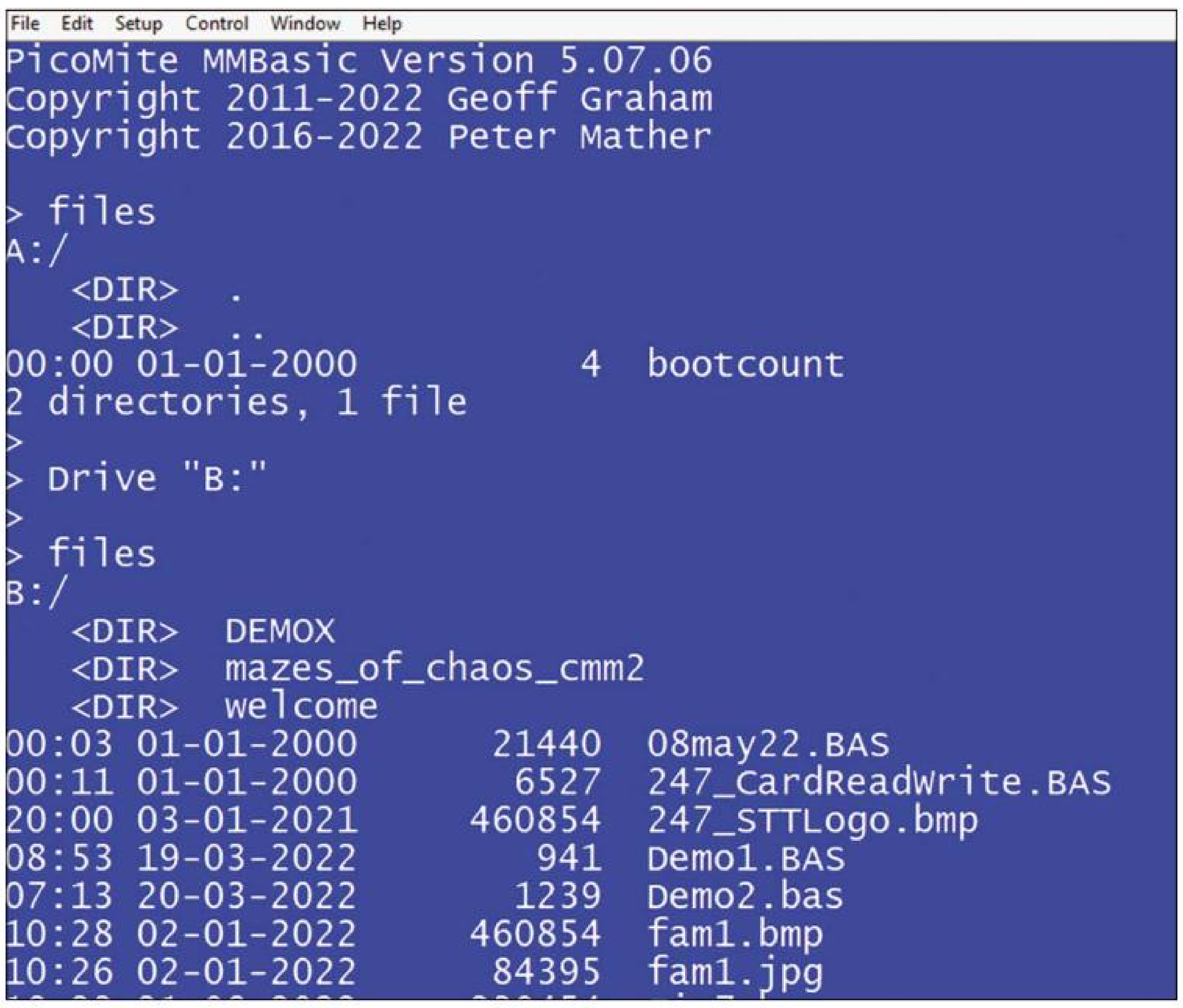

Fig.10. By default (on power-up), the `FILES` command will show any files stored on the internal Flash drive (Drive A).

Having configured the SD card, we would normally test it with the `FILES` command which will display the names of any files stored on the inserted SD card. However, if you try the `FILES` command now, you will see a different result – see Fig.10. This relates to the new feature of file storage mentioned at the beginning of this article. By default (at power up) the `FILES` command will show the files that are stored in the PicoMite's own internal Flash memory (which can be regarded as an inbuilt Flash drive). So, how do we now access files stored on the SD card?

The DRIVE command

There are now two locations that the PicoMite can store files: the new Flash drive (built into the PicoMite's internal Flash memory), and an external SD card (if defined by


File Edit Setup Control Window Help

```
PicoMite MMBasic Version 5.07.06
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> files
A:/
   <DIR>  .
   <DIR>  ..
00:00 01-01-2000         4  bootcount
2 directories, 1 file
>
> Drive "B:"
>
> files
B:/
   <DIR>  DEMOX
   <DIR>  mazes_of_chaos_cmm2
   <DIR>  welcome
00:03 01-01-2000     21440  08may22.BAS
00:11 01-01-2000      6527  247_CardReadWrite.BAS
20:00 03-01-2021    460854  247_STTLogo.bmp
08:53 19-03-2022       941  Demo1.BAS
07:13 20-03-2022      1239  Demo2.bas
10:28 02-01-2022    460854  fam1.bmp
10:26 02-01-2022     84395  fam1.jpg
```

Fig.11. The `DRIVE "B:"` command is used to switch focus to the SD card.

PICOMITE
FINGER PRINT
READER

Fig.12. This is the ‘splash’ screen that will be displayed when the *Fingerprint Reader* is powered up. Also used in the Flash drive demonstration.

using the `OPTION SDCARD` command as we have done above). The Flash drive is referred to as ‘Drive-A’, and the SD card is ‘Drive-B’. To switch between them you simply use the new command `DRIVE`.

So, to select the SD card, simply type `DRIVE “B:”` after which any subsequent command relating to file access will act upon the SD card. Try this by typing `FILES` to confirm that you can indeed see any files stored on the SD card (see Fig.11). Note that `DRIVE “A:”` will switch back to the Flash drive, but for now let’s leave it pointing to the SD card.

The COPY B2A command

Now let’s demonstrate one example of how we can use the new Flash drive storage feature.

Typically, if we want to display an image file on the TFT display, we would use the `LOAD IMAGE “`*`filename$`*`”` command. This would then read the image from the SD card (with the relevant filename) and load it onto the display. However, this means that the SD card (containing the image file) must be inserted whenever we want to load the image to the screen. A possible alternative that we now have is to store the image file in the Flash drive, and use the `LOAD IMAGE` command to load the image file from there instead. This means that the SD card no longer needs to be present (apart from the initial copying of the image file from the SD card into the Flash drive).

Let’ work through the steps to demonstrate this; noting that along the way we will be using another new command: `COPY B2A`.

1. Begin by downloading a copy of the sample image file (**Welcome1.bmp**) from the March 2023 page of the *PE* website (see above). This image is shown in Fig.12; it is what will be displayed on power-up of the completed fingerprint reader.
2. Copy the **Welcome1.bmp** file onto an SD card.
3. Insert the SD card into the socket on the Waveshare display module; then check the file can be seen by typing the `FILES` command. This should reference the B: drive – if not, type `DRIVE “B:”` followed by `FILES`.
4. To copy the image file from the SD card into the Flash drive, enter the command `COPY B2A “Welcome1.bmp” TO “Image1.bmp”`
5. Switch to the Flash drive by typing `DRIVE “A:”`
6. Now type `FILES` to check that the image file is now in the Flash drive (see Fig.13). Note that we renamed the file `Image1.bmp` when we used the `COPY B2A` command in step 4.
7. Remove the SD card from the socket.
8. With the PicoMite still referencing Drive A, type the command `LOAD IMAGE “Image1.bmp”` and it will appear on the display.

The above is just one example of how we can use the built-in Flash drive (instead of an SD card) to store files – in this case, just a single image file. Likewise, we could store some sound files onto the Flash drive (copied initially from an SD card like we did in step 4 above). The PicoMite’s program-code could then trigger the relevant sound file as appropriate without the need for an SD socket in the final circuit build (useful if making a large quantity of a particular product).

Now consider the Pico expander Module we assembled above. This has a PicoMite installed, and a separate display module that includes an onboard SD socket. The arrangement of these two makes a great configuration platform because we can use it to copy any required files from the SD card into the PicoMite’s Flash drive. Once this is done, the PicoMite can be removed and replaced with another one. Then, by repeating the `COPY B2A` process, the second PicoMite’s Flash drive can be loaded with the required files. Repeating this process allows a lot of PicoMites to be configured quickly without the expense of an SD socket in the final project build.

For anyone interested in the other available commands and features regarding the Flash drive, I recommend referring to the latest version of the *User Manual*.

Hardware test

Having assembled the *Fingerprint Reader* hardware on a Pico Expander module, we just need to confirm that everything is connected correctly. For the Waveshare display module, there is nothing really to test since it is simply a plug-in module. During the configuration performed above, the command `GUI TEST LCDPANEL` provided a suitable test to ensure it was working. Likewise, the `DRIVE “B:”` command followed by the `FILES` command checked that the SD-socket was working.

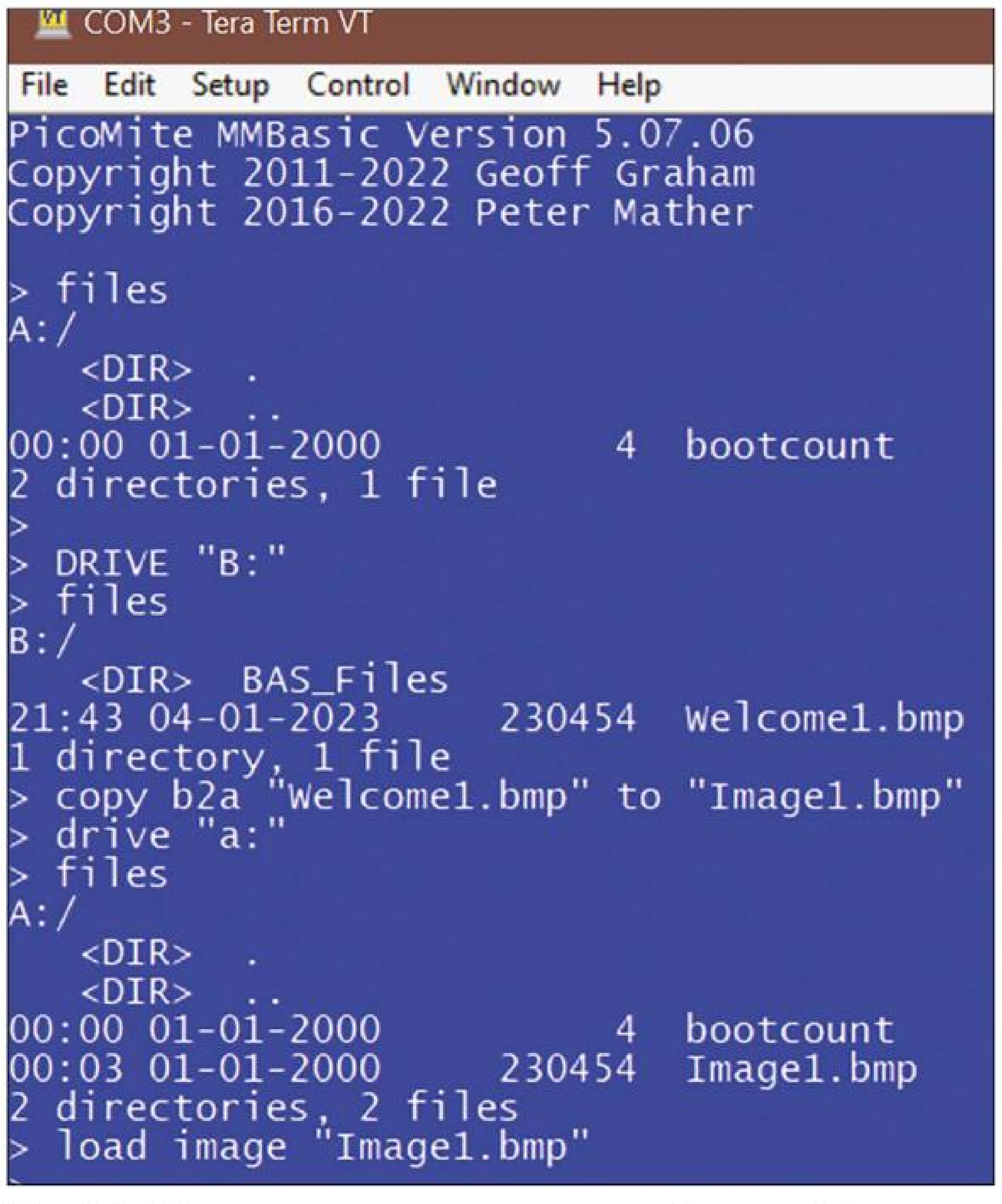
However, the R503 fingerprint module, and the RTC module are connected via DuPont leads – so let us now work through the steps to check these.

R503 test

To check the R503 fingerprint module, we enter a short test program. Type `EDIT` to launch the Editor, and then enter the following five-line program:

```
SETPIN GP2,DIN
DO
  PRINT PIN(GP2)
  PAUSE 100
LOOP
```

Referring to Fig.9, you will see that GP2 is connected to the R503 ‘Finger Detect’ output signal. In the above program, GP2 is set as a digital input (`DIN`), and then a continuous `LOOP` prints the logic level present on this pin (with a delay of 100ms between each ‘sample’). With no finger present, the value 1 should be returned; and when a finger is detected on the R503 sensor, the value 0 should be returned. Now test that this is indeed the case. If not, check the 3.3V power connection to the R503, and also check the connection to GP2. If it is still not working, it is worth removing the Finger Detect signal from GP2, and then with the program



```
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> files
A:/
   <DIR>  .
   <DIR>  ..
00:00 01-01-2000        4  bootcount
2 directories, 1 file
>
> DRIVE "B:"
> files
B:/
   <DIR>  BAS_Files
21:43 04-01-2023   230454  Welcome1.bmp
1 directory, 1 file
> copy b2a "Welcome1.bmp" to "Image1.bmp"
> drive "a:"
> files
A:/
   <DIR>  .
   <DIR>  ..
00:00 01-01-2000        4  bootcount
00:03 01-01-2000   230454  Image1.bmp
2 directories, 2 files
> load image "Image1.bmp"
```

Fig.13. The `COPY B2A` command is used to copy files from the SD card to the Flash drive.

Micromite code

The code in this article is available for download from the October 2022 page of the *PE* website.

still running, use a wire between GP0 and 0V to check it shows a returned value of 0. Likewise, short GP2 to 3.3V and check it shows a value of 1.

To check the Tx and Rx pins, download the test program file **R503ComTest.txt** from the March 2023 page of the *PE* website (go to: **https://bit.ly/pe-downloads**) and load it into the PicoMite. Type `RUN` to launch the test, which will turn on the ring LED with a blue colour. If this is not observed, check the Tx and Rx signals, and switch them over if needed. With everything connected correctly, the LED will be lit blue, and that completes the R503 checks.

RTC test

The first step involves setting the date and time in the RTC module with the `RTC SETIME` *`yy,mm,dd,hh,mm,ss`* command. Use a suitably accurate time source such as an internet-based clock (**https://time.is/GMT**) and replace the parameters shown with the appropriate values. For example, if it is currently 8:36:45PM on 16 February 2023, round up to the next whole minute (or two minutes if more appropriate) and at the command prompt, enter the command as: `RTC SETTIME 23,02,16,20,37,00`

If an error is displayed that states 'RTC not found', then carefully check the four wires connecting the RTC to the PicoMite. There are two power connections (3.3V supply to + and –), and the two I^2C connections going to pins GP20 (D) and GP21 (C). Also check the `OPTION SYSTEM I2C` parameters are `GP20` and `GP21` (use `OPTION LIST` to do this).

Once the time is set in the RTC, power down the PicoMite, and after a few seconds, reapply power.

Now type `RTC GETTIME` to load the RTC's maintained date and time into the built-in system variables `DATE$` and `TIME$`.

With this done, type `PRINT DATE$` followed by `PRINT TIME$` to check that the correct date and time are displayed.

If they are showing correctly then this test is complete. However, if the time is showing `00` for hours and minutes (and the true time is not just after midnight!) then there is an issue, as the time has not been maintained by the RTC. I have only ever experienced this on one occasion and that turned out to be a faulty RTC backup battery.

Next time

Next month, we'll finish the *Fingerprint Reader* with a brief description of the software that we'll be making available. Plus, we'll begin the discussion of our next project, which is based around the popular ESP32 Wi-Fi module.

Until then, stay safe, and have FUN!

Questions? Please email Phil at:
contactus@micromite.org

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82µH, 4.7mH, 100µH, 270µH	£2.00
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Holco H2 2.2MΩ 1W, 1%	£1.00
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Allen Bradley 1.2kΩ 2W C-comp	£1.00

Lots of big valve resistors available.

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Electronically controlled resistance – Part 7

This month, we continue our series on electronically controlled resistance by considering another application of digipots (digital potentiometers), which are digitally controller variable resistors, often, but not always interfaced to microcontrollers. The previous three articles covered the basics of digipots, their characteristics, example devices, modelling in LTspice and their use to control amplifier gain.

The control of amplifier gain, which we discussed last month, is not the only application for digipots. There are of course many possible specific applications – common circuits which could benefit from digipot-based control include voltage regulators and analogue filters. This month, we will look at using digipots with adjustable linear voltage regulator circuits. Replacing the adjustment resistor with a digipot may seem straightforward, but there are some issues that need to be considered and which may not be immediately obvious. These are related to the current and voltage ratings, available component values and tolerance, which are parameters that may to be of concern in other types of circuit where digipots are considered.

Three-terminal regulators

A common form of adjustable regulator circuit is shown in Fig.1. Regulator integrated circuits of this type are often referred to as '3-terminal regulators', reflecting the minimal pin count. We will look at using a digipot for R_2 (which adjusts the output voltage).

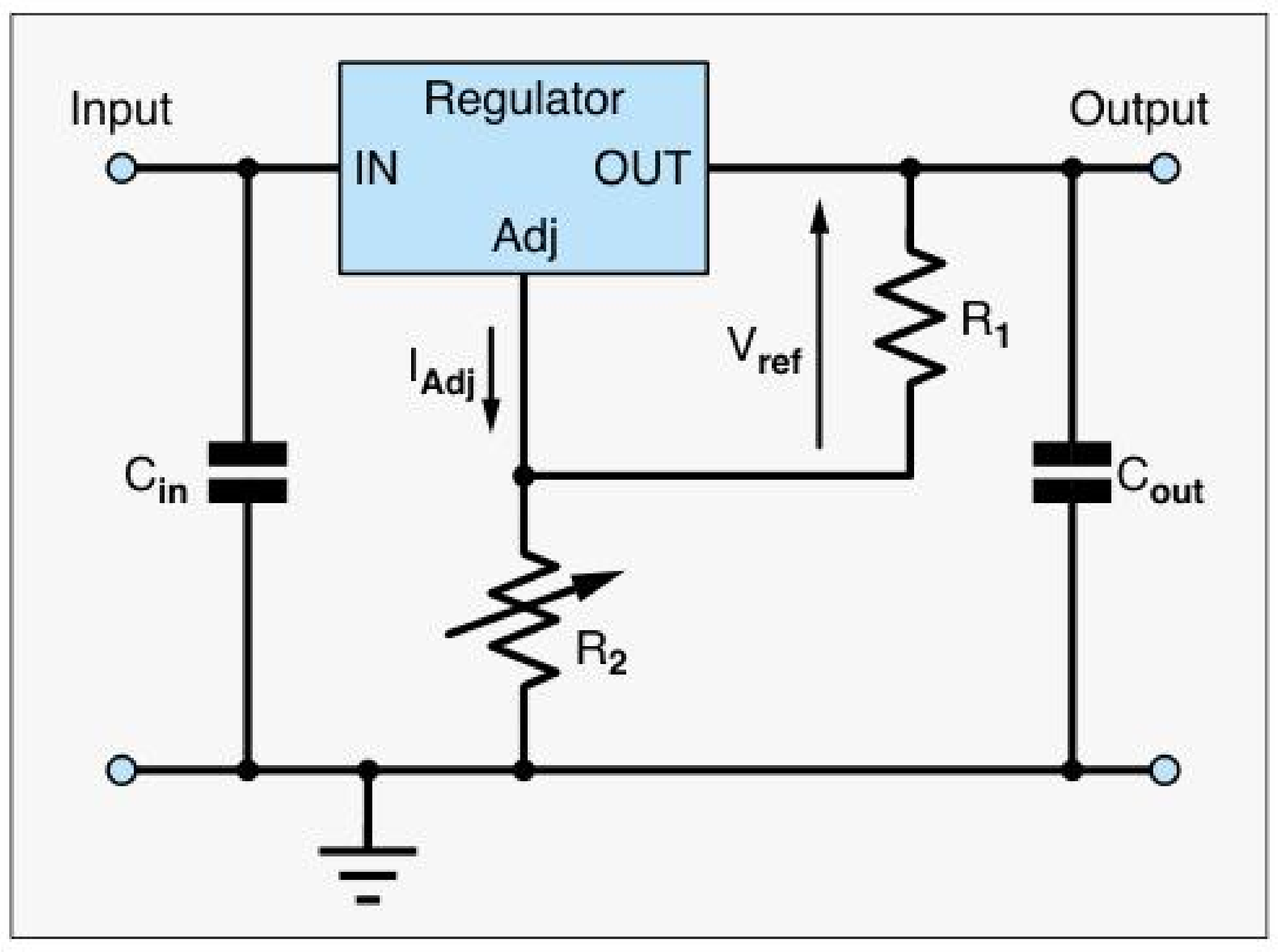


Fig.1. Typical 3-terminal voltage regulator circuit.

The regulator in Fig.1 uses an internal voltage reference circuit to provide a point of comparison with the (scaled) output voltage. A feedback control circuit, typically implemented using an internal op amp, regulates the voltage between the Out and Adj pins to be equal to the reference voltage (V_{ref}). If the Adj pin is connected directly to ground the output is regulated to be equal to V_{ref}. If adjustment resistors (R_1 and R_2) are included (as shown in Fig.1) then the output voltage is regulated to the voltage at the Adj pin plus V_{ref}.

The voltage across R_1 is equal to V_{ref}, so the current through it is $I_{R1} = V_{ref}/R_1$. If we ignore the current required by the Adj pin (I_{adj}) the same current flows in R_1 and R_2, so the voltage across R_2 is $I_{R1}R_2 = V_{ref}R_2/R_1$. The output voltage is the voltage across R_2 plus the reference voltage, so:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right)$$

The current in the adjustment pin adds an additional contribution to the voltage drop across R_2, which also adds to the output voltage, giving a more accurate formula for V_{out}, as:

$$V_{out} = V_{ref}\left(1 + \frac{R_2}{R_1}\right) + I_{adj}R_2$$

However, the adjustment pin current is typically in the order of 50 to 100µA, and with the typical values of the resistors being in the hundreds of ohms range the value of $I_{adj}R_2$ is small and can often be ignored.

Example designs

The typical value for R_1 in reference designs (for example, in device datasheets) is in the order of 100Ω to 300Ω, with 121Ω and 240Ω being very commonly used. For example, R_1 = 121Ω and R_2 = 365Ω and V_{ref} = 1.25V gives V_{out} = 5V. These examples typically use R_1 as a fixed resistor and R_2 as a single variable resistor, which implies use of a digipot in rheostat mode.

The LM317 is probably the best-known device of this type. The LT1085 is similar, but is 'low drop out' (LDO), which means that a smaller difference in voltage between input and output is required to maintain operation (V_{in} needs to be about 3V above V_{out} for the LM317, but only 1V for the LT1085, giving superior efficiency). The LT1085 can provide up to 3A output current and has a V_{ref} value of 1.25V.

As an example design, consider adjustable output up to 15V using an LT1085. If we use the typical value of R_1 of 121Ω then 15V requires R_2 = 1.33kΩ, which we can find by rearranging the V_{out} equation above:

$$R_2 = R_1\left(\frac{V_{out}}{V_{ref}} - 1\right)$$

We also need a minimum input voltage of about 16V.

First simulation example

For simulation purposes we can select ten different values, stepped from 133Ω to R_2 = 1.33kΩ in 133Ω steps. The specific values do not matter too much for illustrative purposes – we are not aiming to show all

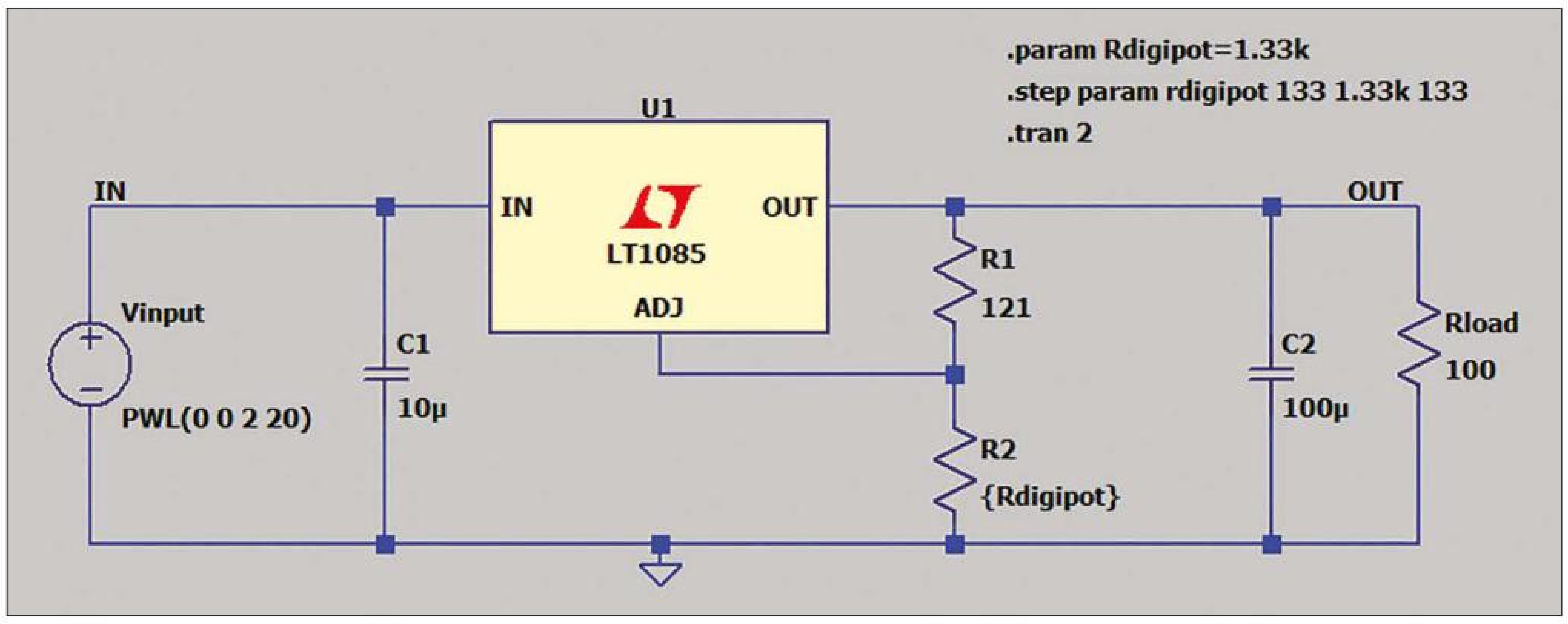


Fig.2. Possible use of a digipot with a 3-terminal regulator (see text for issues).

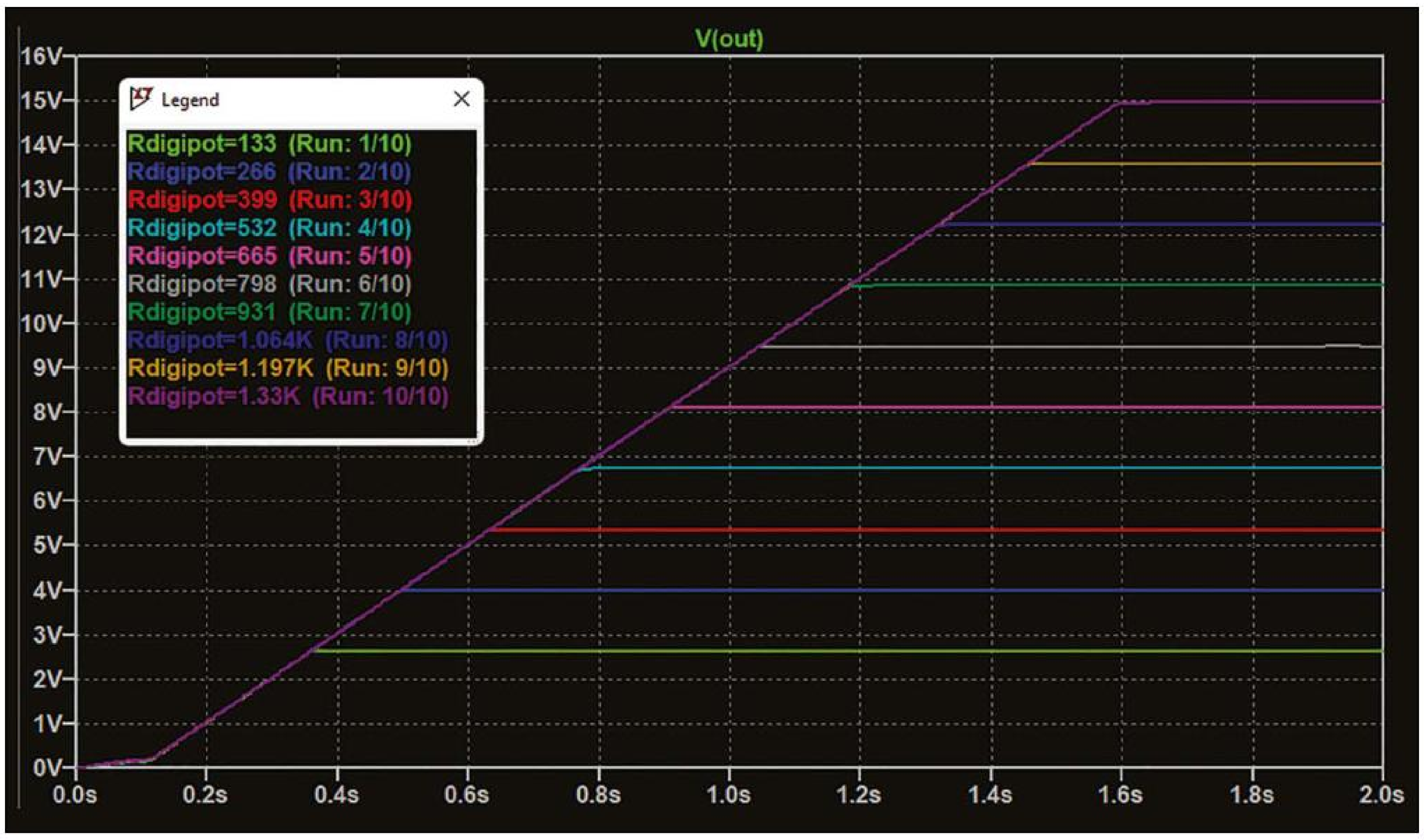


Fig.3. Simulation results from the circuit in Fig.2 showing output for various resistance values.

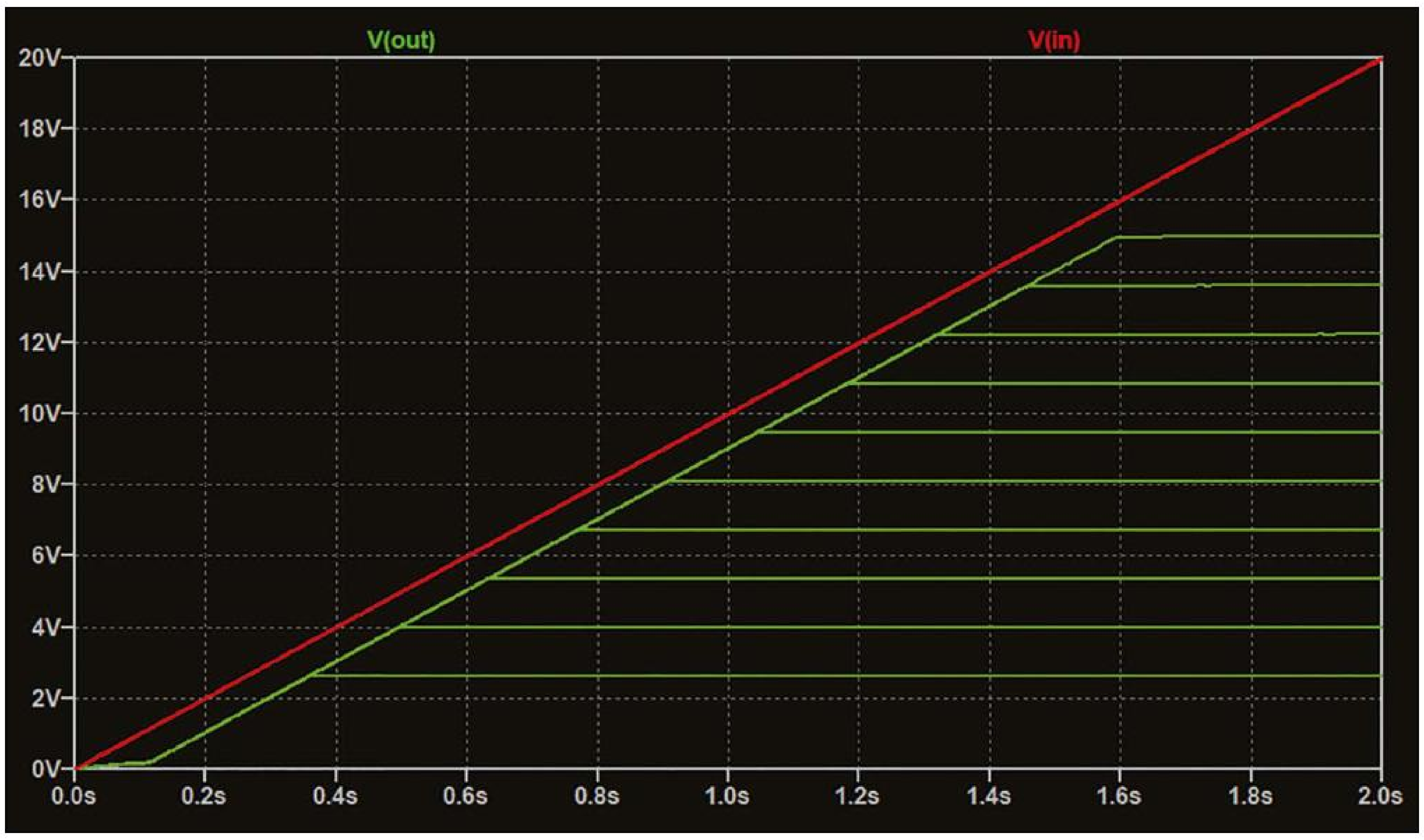


Fig.4. Simulation results from the circuit in Fig.2 showing input-output relationship (input: red trace; outputs: green traces).

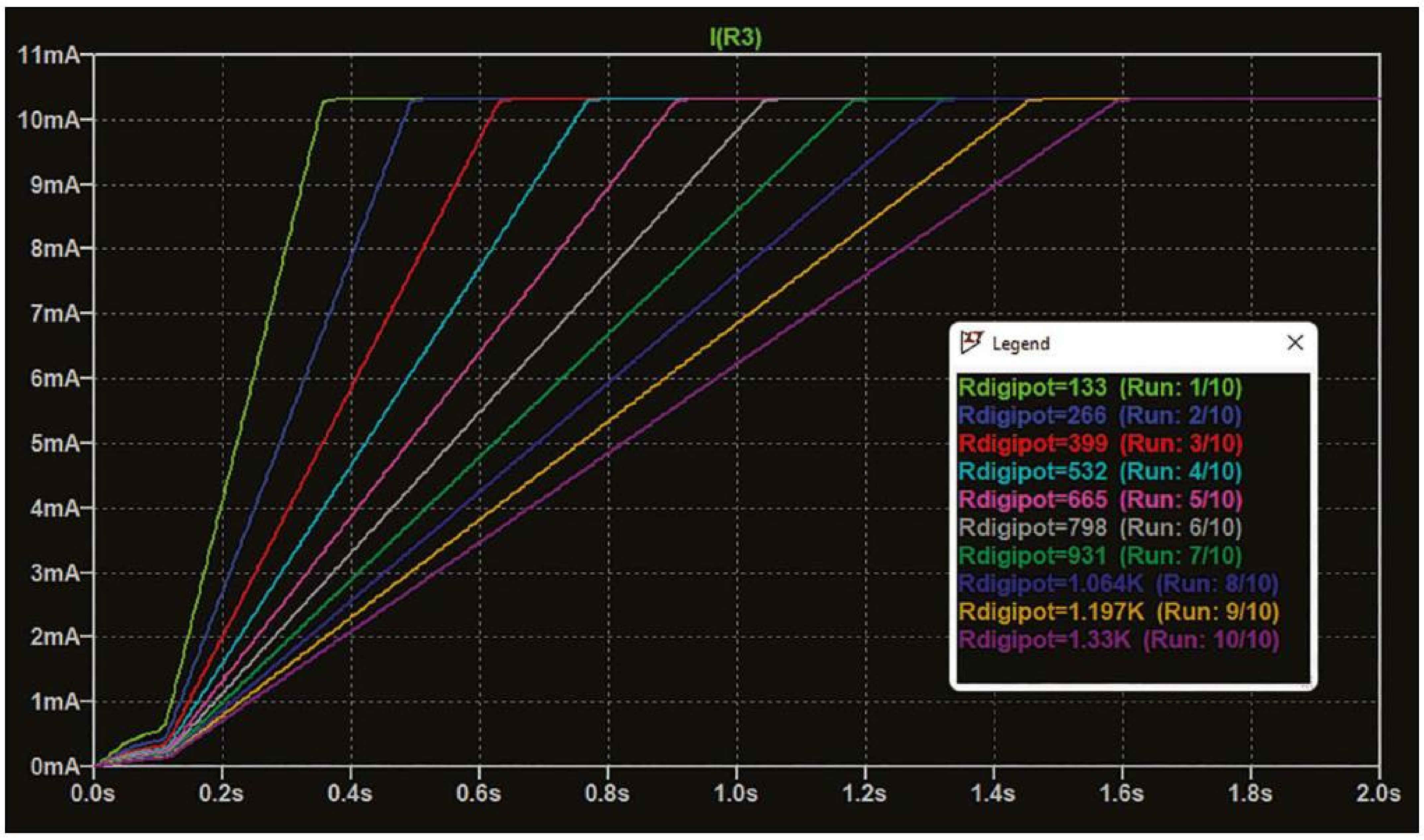


Fig.5. Digipot resistor current for the circuit in Fig.2.

the possible steps of the typical digipot. Furthermore, a digipot with an end-to-end resistance of 1.33kΩ is unlikely to exist; however, devices with a resistance larger than this can be used with the setting restricted to the required values. Not using the full range of values is also often necessary in rheostat mode to account for the device resistance tolerance – as we discussed in *Part 5*.

An LTspice schematic for this circuit is shown in Fig.2. This is similar to example designs given in datasheets, where it is assumed that a standard mechanical potentiometer is used for R_2. The digipot is modelled using a stepped-resistor parameter – the behavioural resistors discussed previously are not required here as only a single resistor is required to model the digipot in rheostat mode. The simulation ramps the input voltage from 0 to 20V over two seconds. The time is not particularly important, but two seconds gives a simple time-to-voltage relationship.

The results of the simulation are shown in Fig.3 – the step command plots a set of different results as `Rdigipot` is varied. The result show that the output voltage is regulated once the input voltage rises about 1V above the set output voltage, so, for example, the 15V output (`Rdigipot` = 1.33kΩ) appears after about 1.6s and the other voltages at proportionally earlier times. This can be seen more clearly in Fig.4, where the input voltage is also plotted (but this makes it harder to identify the individual stepped traces).

Digipot current

Fig.5 shows the current in the digipot. Once regulation is established (for a sufficiently large input voltage) the current is constant at about 10.3mA. This is equal to V_{ref}/R_1 = 1.25/121 = 10.33mA. The problem with this is that this current is higher than the maximum continuous current rating for many digipots, which may be 5mA or 1mA. Low resistor values are used in standard versions of this circuit, partly to ensure that the resistor current is much larger than the adjustment pin current (55µA to 120µA for the LT1085) and partly to take the minimum load current from the regulator output (5mA to 10mA for the LT1085). The resistors can be made larger to reduce the current, and, if necessary, an additional load resistor could be added to ensure minimum current.

It may be possible to overcome the maximum current problem by using a parallel resistor with the digipot. This is shown in Fig.6, which is a modified version of Fig.6. For a required maximum effective value of R_2 (the total parallel resistance for the maximum output voltage to be used) and a digipot value of R_D the parallel resistor value can be found using the parallel resistor formula rearranged to give R_P:

$$\frac{1}{R_P}=\frac{1}{R_2}-\frac{1}{R_D}$$

If we use a larger value of R_1 (than in Fig.1) of 240Ω then we need R_2 = 2.64kΩ for V_{out} = 15V. For a 5kΩ digipot (R_D) the value of R_P is 1/(1/2640 – 1/5000) = 5.56kΩ (as shown in Fig.6).

Simulation results are shown in Fig.7, which confirm that the circuit is able to

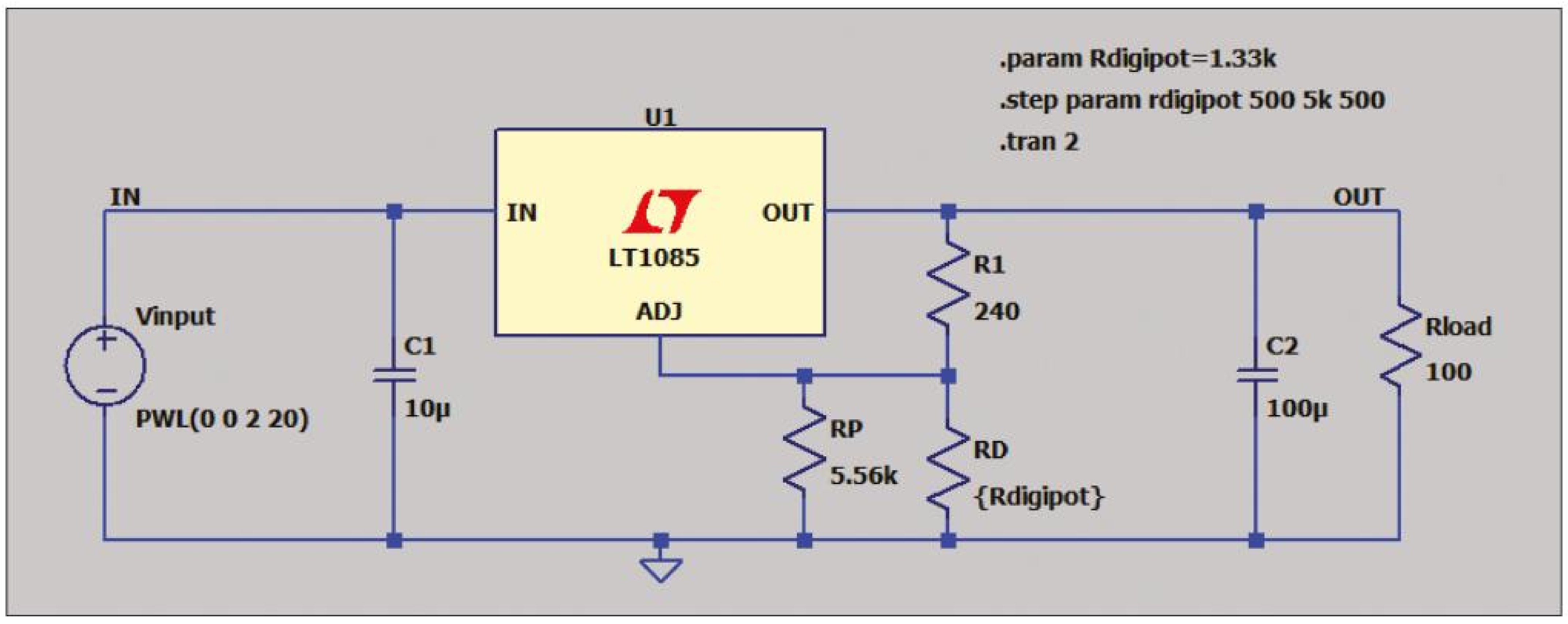


Fig.6. Modified version of the circuit in Fig.2 with reduced digipot current.

control the output voltage over a similar range to the circuit in Fig.2. However, notice that the relationship between the resistor step value (which corresponds to the digipot code) and the output voltage is no longer linear (output voltage steps are not equally spaced) due to the use of the parallel resistor combination to set the effective R_2 value. The results in Fig.8 confirm the reduction in current through the digipot, which remains below 5mA over the range of input and output voltages covered

Accuracy

As we discussed in previous articles, digipots often have much worse tolerance for their absolute resistance value than is readily available for fixed resistors. In potentiometer mode, where the ratio of the two resistances from the wiper to the two ends controls the circuit, the excellent matching of the on-chip resistors to each other can lead to very good design tolerance. However, in rheostat mode, as used here, that does not apply.

Using a digipot in rheostat mode in parallel with accurate fixed resistors reduces errors due to digipot tolerance, so this is another benefit of the circuit in Fig.6 over that in Fig.2. Use of series resistances with digipot in rheostat mode also has the same effect. We previously discussed use of series resistors to reduce the control range to allow more precise control of a circuit – it is often worth considering use of digipots in combination with fixed resistors to improve or better tailor the control of the circuit.

If we assume the fixed resistors have negligible error in value and the digipots have a 10% tolerance, then we can calculate the variation in output voltage for the two worst-case digipot resistance values (at ±10%). This is just a matter of applying the V_{out} equation with the relevant highest and lowest digipot tolerance values, and, in the case of the circuit in Fig.5 applying the parallel resistor formula to obtain the effective R_2 value. This gives a variation of about 9.2% for the circuit in Fig.2 and worst-case of 5.1% for the circuit in Fig.6 for the 15V output setting, which is a significant improvement.

Alternative regulators

There is another major problem which may make the circuits in Fig.2 and Fig.6 impractical – at least for the voltage ranges used here – which is the maximum voltage across the digipot. Many digipots have maximum supply voltages of 5V (maybe 5.5V absolute maximum) and typically the maximum voltage across the resistor chain is equal to, or very similar to the supply voltage. Devices with 15V are available but tend to have larger resistor values, which may be less suitable in the type of regulator in these examples.

Not all adjustable regulators are 3-terminal devices. Often, regulators have an adjustment input which is separate from the regulator ground – a typical circuit is shown in Fig.9 which features the LT1121. The LT1121 is a micropower LDO regulator capable of supplying

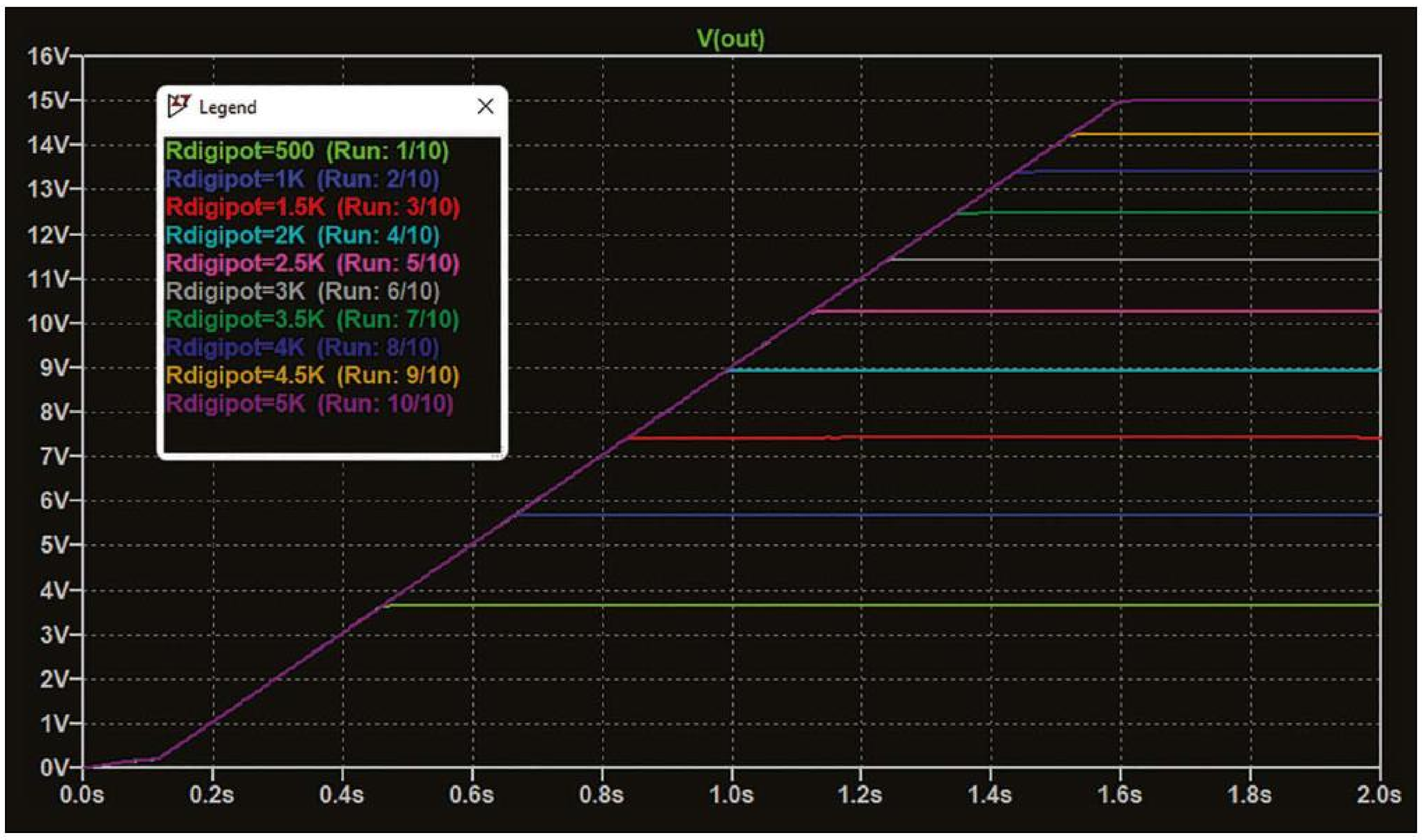


Fig.7. Simulation results from the circuit in Fig.6.

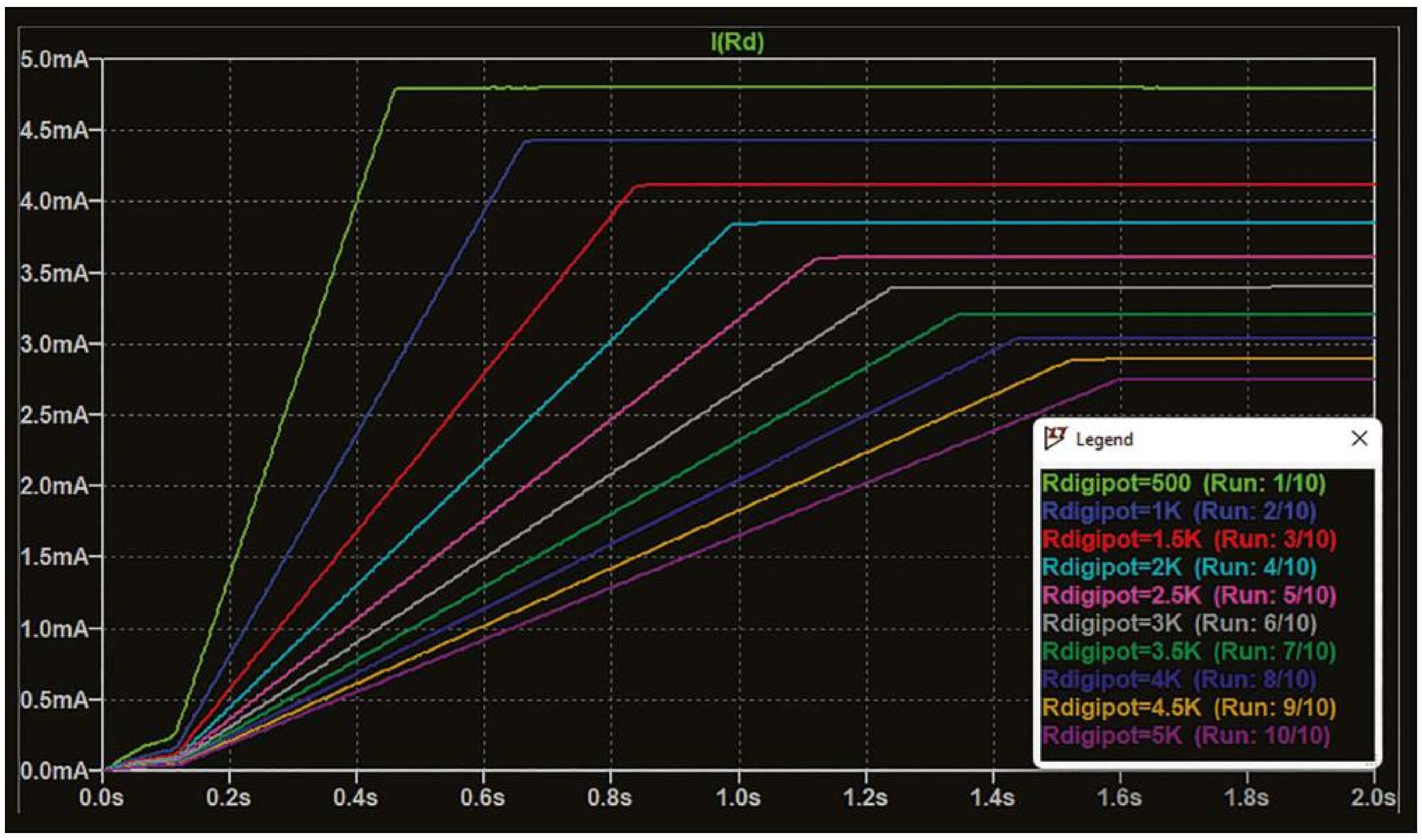


Fig.8. Digipot resistor current for the circuit in Fig.6.

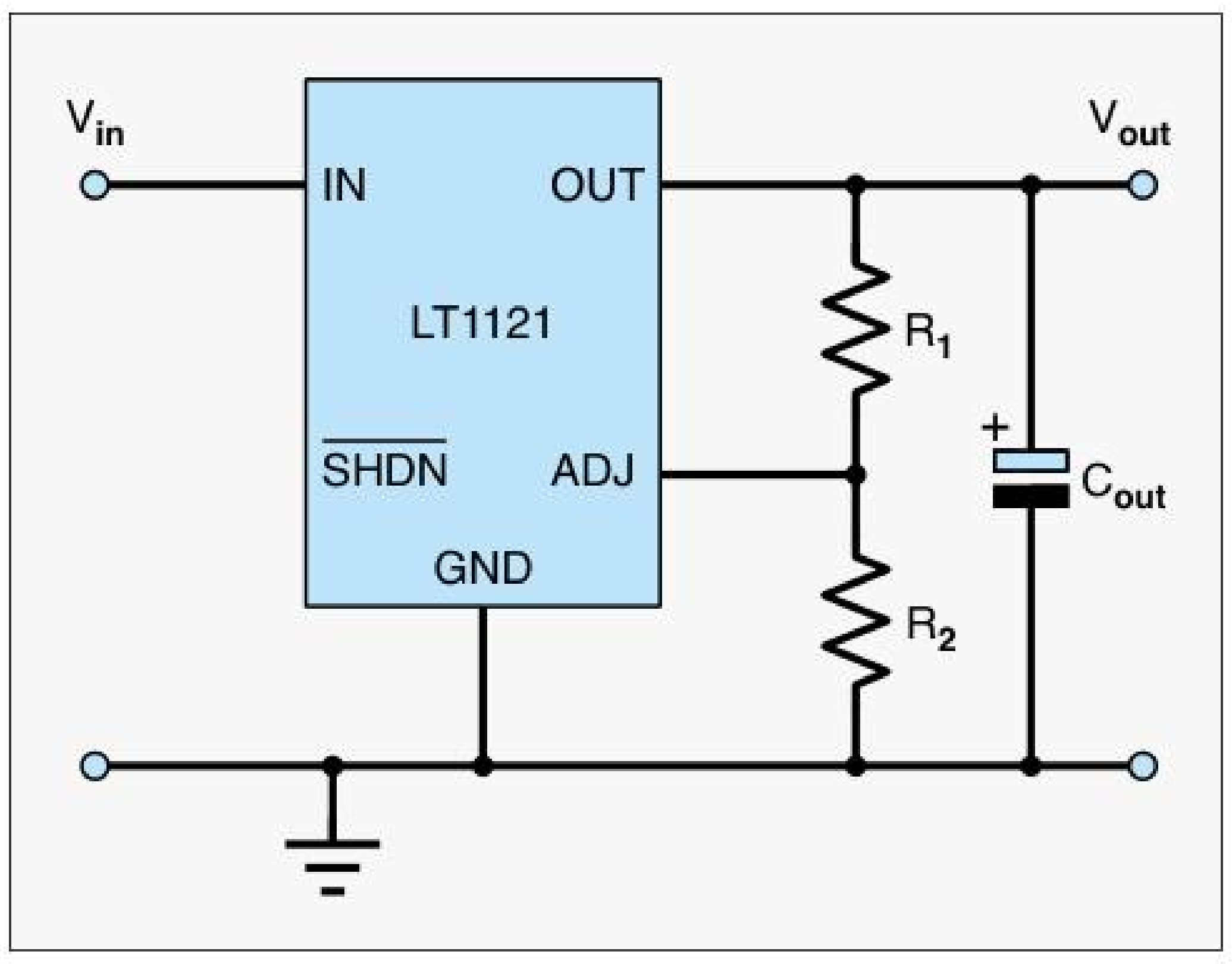


Fig.9. Typical adjustable regulator circuit for a device with separate adjust and ground pins.

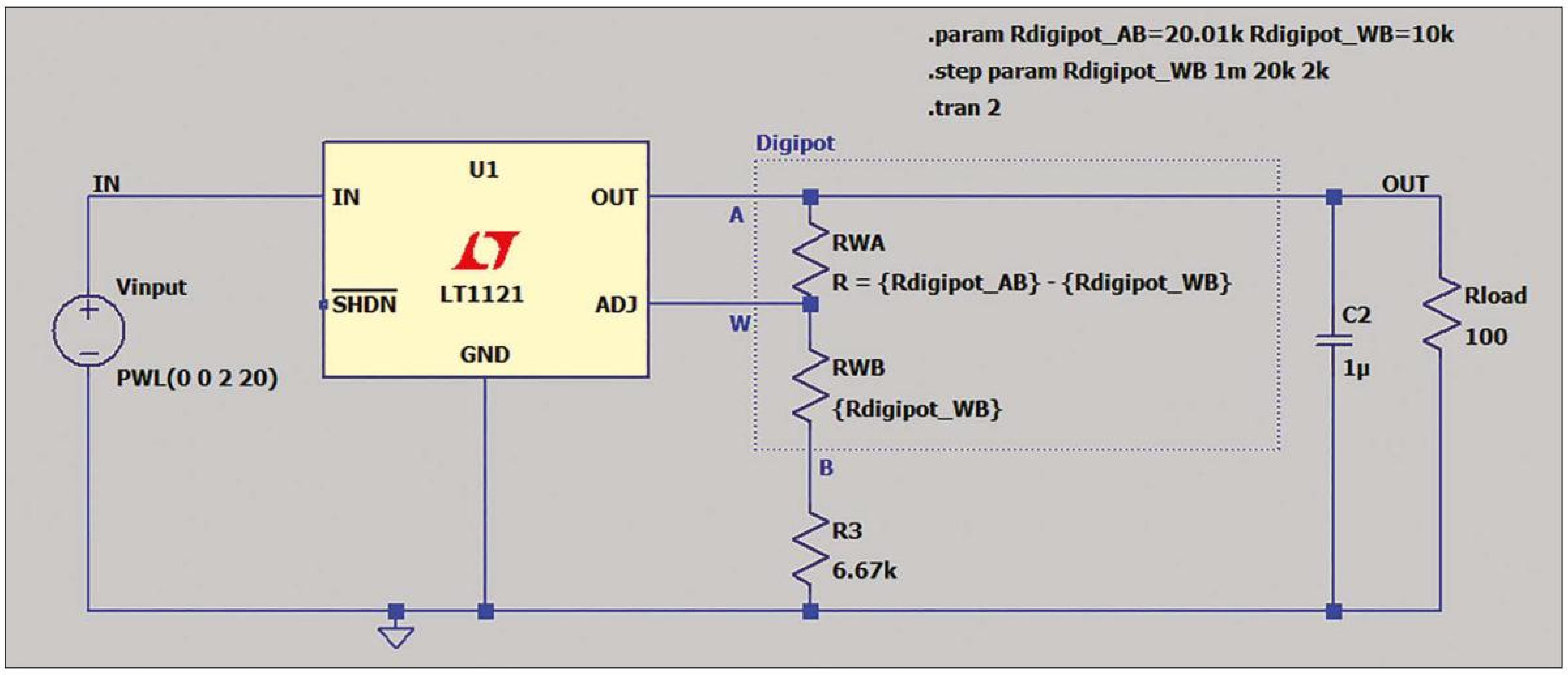

.param Rdigipot_AB=20.01k Rdigipot_WB=10k
.step param Rdigipot_WB 1m 20k 2k
.tran 2
IN
U1
IN
OUT
Vinput
SHDN
LT1121
ADJ
GND
PWL(0 0 2 20)
Digipot
A
W
RWA
R = {Rdigipot_AB} - {Rdigipot_WB}
RWB
{Rdigipot_WB}
B
R3
6.67k
OUT
C2
1µ
Rload
100

Fig.10. LTspice schematic for an LT1121 regulator with digipot control.

150mA of output current with a dropout voltage of 0.4V. The output voltage is adjustable from 3.75V to 30V (fixed output versions are also available). The device has a 5V logic, active-low shutdown pin (output turned off if shutdown is driven below about 0.6V). The shutdown pin can be floating if not used.

Internally, the adjustment pin is connected to the control circuit input. The control circuit adjusts the output voltage to obtain 3.75V at the adjustment pin. Like the LT1085, some current flows into the adjustment pin. This is about 150nA for the LT1121, much smaller than the LT1085 and similar devices, which facilitates use of larger resistors in the feedback network (R_1 and R_2 in Fig.9).

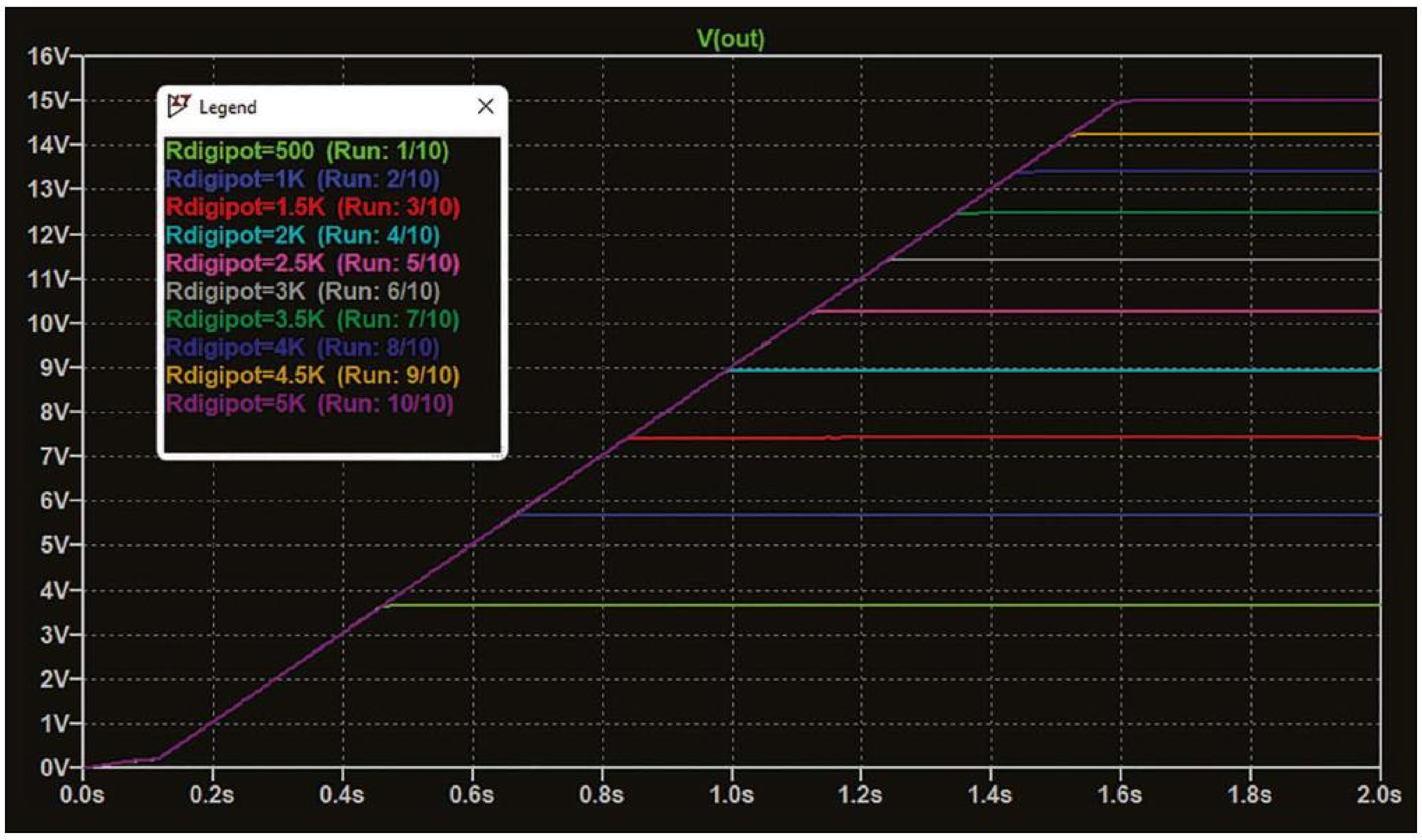


Fig.11. Simulation results from the circuit in Fig.10.

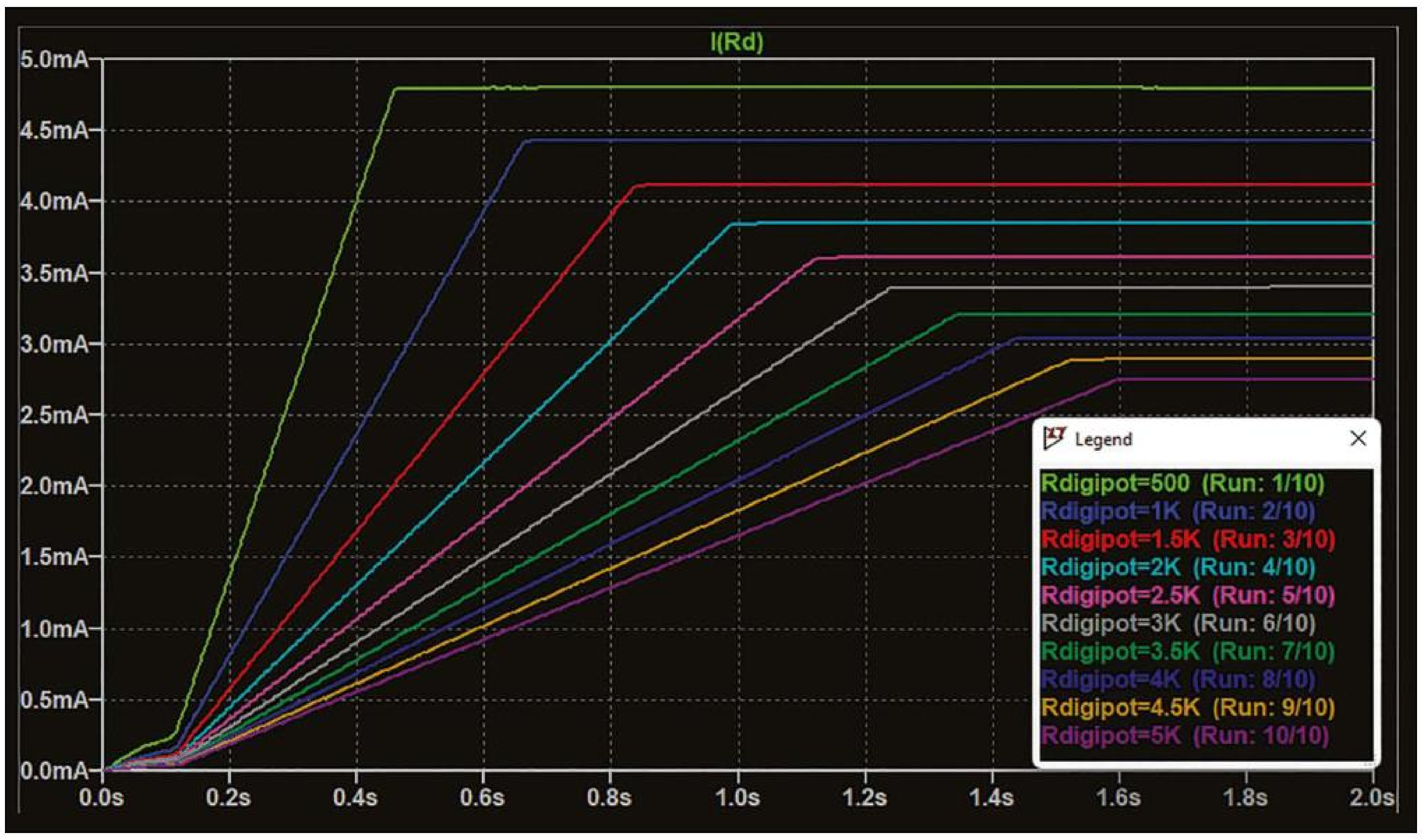


Fig.12. Digipot resistor current for the circuit in Fig.10.

Circuit operation

The operation of this circuit is similar to the circuit in Fig.1 except the reference voltage (3.75V) is between ground and the adjustment pin, rather than the output and the adjustment pin. The voltage across R_2 sets its current (and the current in R_1) to $3.75/R_2$ and so the output voltage is:

$$V_{out} = 3.75\left(1+\frac{R_1}{R_2}\right)$$

Note that the resistor ratio in the formula is the opposite way round compared to the formula for the circuit in Fig.1, with the resistors numbered similarly. To avoid confusion, if you consult the datasheet, also note that this uses a different resistor numbering.

Like the previous circuit, an error voltage of $I_{adj}R_1$ can be added to V_{out} to account for the adjustment pin current if required. The datasheet states that the value of R_2 should be less than 400kΩ, so a 20kΩ is easily suitable and may be available for 15V device. A 50kΩ or 100kΩ digipot could also be used.

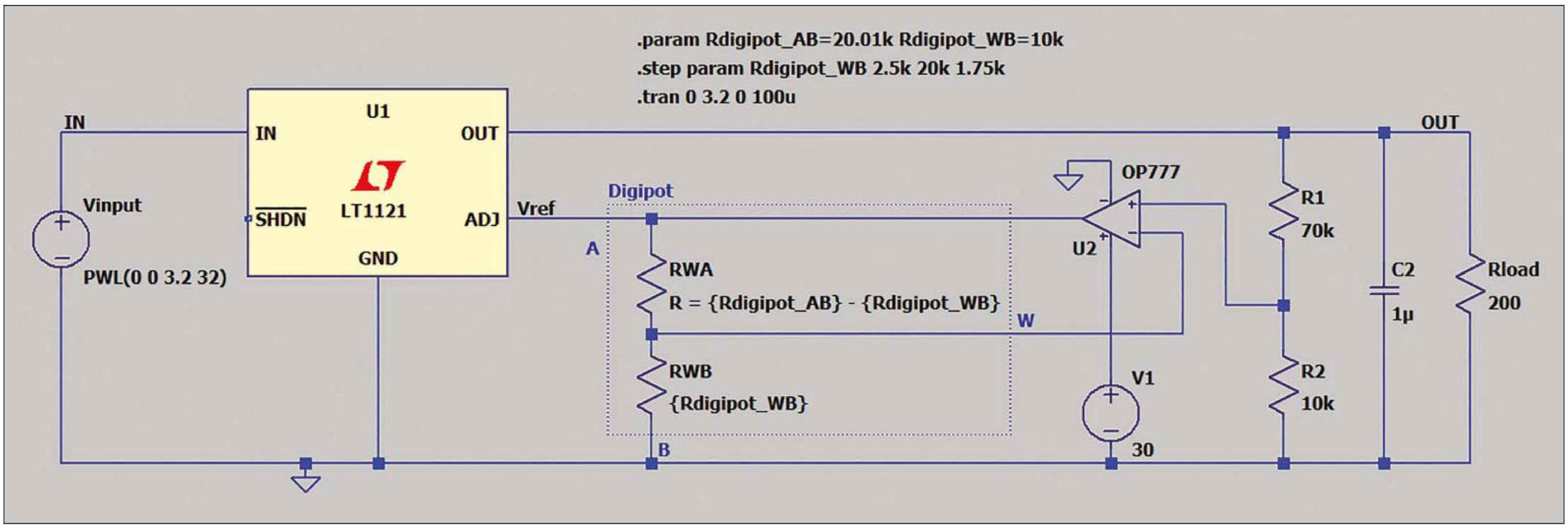
Fig.10 shows an LTspice schematic of the LT1121 circuit with digipot control. The digipot is in potentiometer mode and has a resistance of R_{AB}. There is a resistor (R_3) between the digipot and ground – this sets the maximum output voltage when the digipot wiper is fully at the B end, where the effective value of R_1/R_2 in the above formula is R_{AB}/R_3. If we want a maximum output voltage of 15V then we need $R_1/R_2 = 3$ (because $3.75 \times (1 + 3) = 15$), so with $R_{AB} = 20k\Omega$ we get $R_3 = R_{AB}/3 = 6.67k\Omega$. When the digipot is fully at the A end R_1 (= R_{WA}) is zero (ideally) so $V_{out} = 3.75V$.

Simulation models

The digipot in Fig.10 is modelled using two parameters. The total resistance (R_{AB}) is parameter `Rdigipot_AB`. The resistance between the wiper and B terminal (R_{WB}) is parameter `Rdigipot_WB`. One of the digipot resistors is simply equal to `Rdigipot_WB`, the other (wiper to A terminal, R_{WA}) is calculated using a behavioural resistor with value:

```
R = {Rdigipot_AB} - {Rdigipot_WB}
```

The simulation steps `Rdigipot_WB` through a set of values to give a simulation similar to the other examples above. As discussed when we used behavioural resistors in *Part 5*, it is necessary to ensure that the calculated value resistor is never zero, so the first stepped value of `Rdigipot_WB` is 1mΩ rather than zero. Also, `Rdigipot_WB` is a little larger than 20kΩ to prevent the subtraction returning zero.



```
.param Rdigipot_AB=20.01k Rdigipot_WB=10k
.step param Rdigipot_WB 2.5k 20k 1.75k
.tran 0 3.2 0 100u
```

Fig.13. LTspice schematic for digipot regulator control with lower digipot supply voltage requirements.

Simulation results are shown in Fig.11. The basic pattern is similar to the previous examples, but the steps are non-linear. This may make it difficult to set specific values at the higher voltage end (depending on the number of wiper positions). The situation can be improved with series and parallel resistances and was discussed in the context of amplifier gain last month. The results in Fig.12 show a much lower digipot current than in the previous examples – under 600µA at all points.

Lower digipot supply

The circuit in Fig.10 has a low digipot current but does not allow the digipot to control the full output range of the regulator (up to 30V) because the full output voltage occurs across the digipot. Most digipots have maximum supply voltages below 15V. A possible solution to this is provided in an article by Robert Swartz in *Electronic Design* (January 2016): *Extend Low-Voltage Digipot Resolution to Control an Adjustable Regulator*. A version of this technique applied to the LT1121 is shown in Fig.13.

The circuit in Fig.13 contains an additional op amp in the regulation control loop, which ensures that the potential divider voltage from R_1 and R_2 is the same as the potential divider voltage for the digipot (the two inputs to op amp U2), thus:

$$V_{out}\left(\frac{R_2}{R_1+R_2}\right)=V_{ref}\left(\frac{R_{WB}}{R_{WB}+R_{WA}}\right)$$

$$V_{out}=V_{ref}\left(1+\frac{R_2}{R_1}\right)\left(\frac{R_{BW}}{R_{WB}+R_{WA}}\right)$$

At the same time, the regulator's internal circuitry ensures that the adjustment pin is at the reference voltage (V_{ref}, which is equal to 3.75V for the LT1121). The digipot is connected between the adjustment pin and ground so it has a constant 3.75V across it, which should be no problem for devices running from 5V supplies.

As discussed last month, if we define the wiper position as a value N, where $N = 0$ with the wiper at B and $N = 1$ when the wiper is A, then the digipot potential divider function becomes NV_{ref}, so we have:

$$V_{out}=3.75N\left(1+\frac{R_2}{R_1}\right)$$

Design calculations

The ratio of R_1 and R_2 sets the maximum output voltage for the wiper position $N = 1$. For an output of 30V (the maximum for the LT1121) we need $R_1/R_2 = 7$ (because $3.75 \times 1 \times (1 + 7) = 30$). The circuit in Fig.13 uses 70kΩ and 10kΩ to achieve this. The output voltage is linearly dependent on the wiper position, which is an advantage over the circuit in Fig.10.

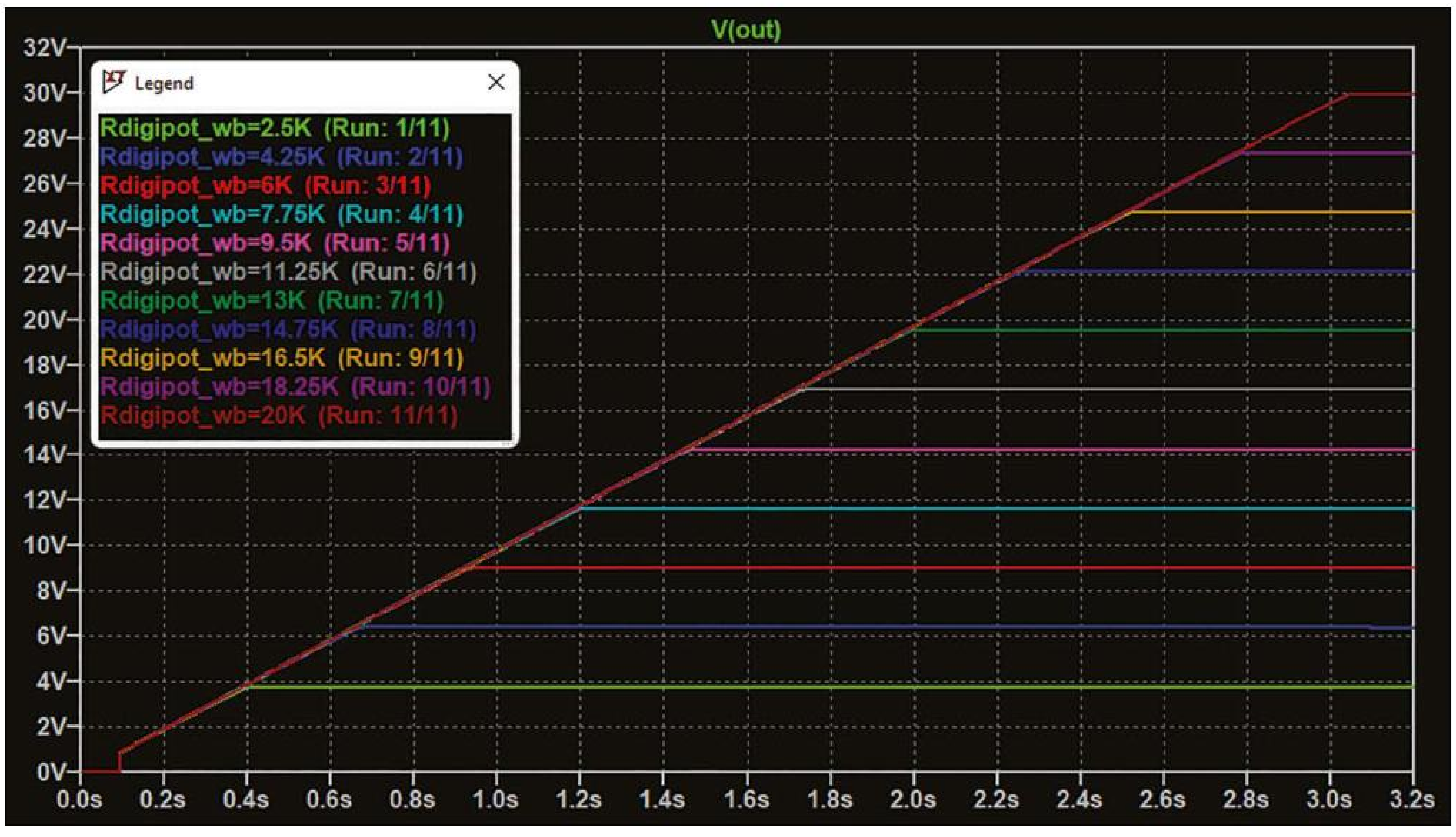


Fig.14. Simulation results from the circuit in Fig.13.

The circuit can operate with values of N which give V_{out} at 3.75V or more. With $R_1/R_2 = 7$ the minimum value of N is $R_{AB}/8$. For a 20kΩ digipot this is 2.5kΩ – the R_{WB} resistance (`Rdigipot_AB` parameter) in the simulation is stepped from this minimum value to account for this. In a real system this would have to be ensured by the software. Alternatively, a suitable resistor can be placed in series with the digipot, in a similar way to R_3 in Fig.10, which allows the full range of the digipot to be used.

Simulation results are shown in Fig.14. Again, this is similar to previous results, but shows the larger output range of 3.75V to 30V and the linear relationship between the digipot setting at the output voltage (evenly spaced output voltage traces). This circuit requires more components (particularly the op amp) but provides significant advantages over the others discussed above. The fixed voltage across the digipot (once the input voltage is sufficient for the regulator to operate) leads to a constant current through the digipot of $V_{ref}/R_{AB} = 3.75/20k = 188µA$.

The discussion in this article has focused on the use of digipots to control voltage regulators. We have not discussed all aspects of the circuits, for example selection of suitable values for the capacitors. Some regulator circuits may require additional components which have not been included in the schematics here – for example, protection diodes. In all cases, device datasheets and other relevant technical document from device manufacturers should be consulted when developing designs.

Simulation files

Most, but not every month, LTSpice is used to support descriptions and analysis in *Circuit Surgery*.
The examples and files are available for download from the *PE* website.

Max's Cool Beans

By Max the Magnificent

Arduino Bootcamp – Part 3

I like things to be logical. One of the reasons I enjoy playing with microcontroller units (MCUs) like the Arduino is because the way they work inside is based on logical functions and the programs we run on them behave in a logical manner (on a good day… if we're lucky).

I also enjoy mulling over logical conundrums. For example, did you ever see the 1986 fantasy film *Labyrinth?* This movie is full of riddles and puzzles, including one involving two doors, each with a guard. One door leads to where we want to go while the other leads to certain death. We can pose a single question to just one of the guards to help us determine which door we wish to use. The problem is, although we know one guard always tells the truth and the other always lies, we don't know which is which. So, what question should we ask? (The answer is at the end of this column.)

Roll your own

By some strange quirk of fate, shortly after I commenced penning this piece, my old chum Alvin Brown sent me a link to a review on the Tom's Hardware website (**https://bit.ly/3WbawFo**). You can only imagine my surprise and delight to discover that this review features a *Build Your Own Arduino Uno Kit*. (In addition to the Uno itself, the kit includes an Audio Synthesiser 'shield' (a board that plugs on top of the Arduino) that you can build and use to make sounds or music.

If you are just starting out with microcontrollers (which would explain your barely controlled excitement at the thought of reading this column), you might want to leave building your own Arduino for later. On the other hand, you must agree that it would be mega-cool to be performing the experiments in these columns on an Arduino Uno we'd actually built ourselves.

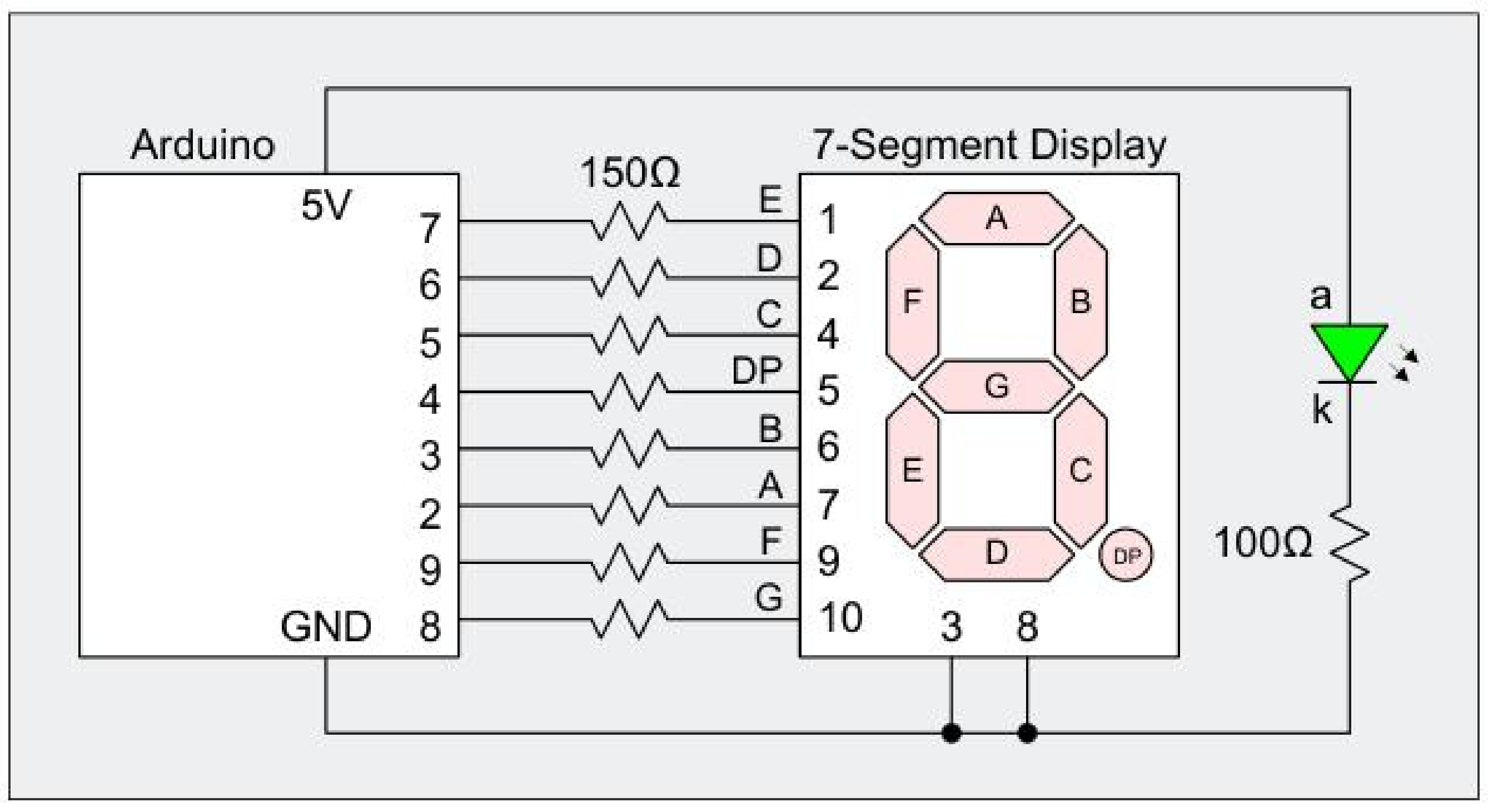


Fig.1. Circuit diagram showing the current state of play.

Great Scottish bagpipes!

Speaking of bagpipes (we weren't, but we are now), let's pretend we are in a marching band, in which case it's important to ensure we're all marching in step to the same drumbeat.

As you may recall, in *Part 1* of this mega-miniseries (*PE*, January 2023), we plugged a single green light-emitting diode (LED) into our breadboard, along with a 100Ω current-limiting resistor. We use this LED (a) because we love LEDs and (b) to provide a visual indication that power is reaching the breadboard.

In *Part 2* (*PE*, February 2023), we plugged a single-digit common-cathode 7-segment display into our breadboard, connected 150Ω current-limiting resistors to each of this device's anode terminals, and connected the other side of those resistors to some of the Arduino Uno's digital input/output (I/O) pins, which we configured to act as outputs.

A circuit diagram reflecting the current state of play is shown in Fig.1. This is obviously an abstraction that reflects much-simplified views of our real-world Arduino and 7-segment display. Different people will draw these diagrams in different ways, but the gist will always be the same. It's important for you to learn how to parse this sort of diagram and wrap your brain around the underlying functionality it's intended to convey.

A more 'real-world' depiction of our breadboard's layout and wiring – including the connections between the breadboard and the Arduino Uno – is illustrated in Fig.2. Take a moment to compare and contrast the different views of the design provided by these two representations and make sure that everything makes sense.

Before we proceed, connect the USB cable powering your Arduino. Assuming your host computer is powered up and you've left everything 'as is' from our previous experiments, the green power LED on the right-hand side of the breadboard should light up. Also, the last program we loaded into the Arduino should start randomly lighting the segments on the 7-segment display.

Too much power!

We're not going to go through the calculation to determine the minimum value of an LED's current-limiting resistor again because – as we discussed in *Part 2* – you should have this documented in your logbook. Suffice it to say, our green LED's forward-voltage drop (V_F) is specified as being 3V and its maximum forward current (I_F) is 20mA. Based on this, we decided to use a 100Ω resistor (Fig.1). This value is reflected in the resistor's brown-black-brown colour bands (Fig.2).

Using the maximum current isn't a problem per se, except for the fact that the LED may be a tad too bright for our viewing pleasure. On the other hand, it's not good practice to drive an electronic component at any of its maximum rated values. For example, LEDs tend to dim with age and this dimming is exacerbated if we constantly run them at their maximum rated current value. In this situation, we might want to double

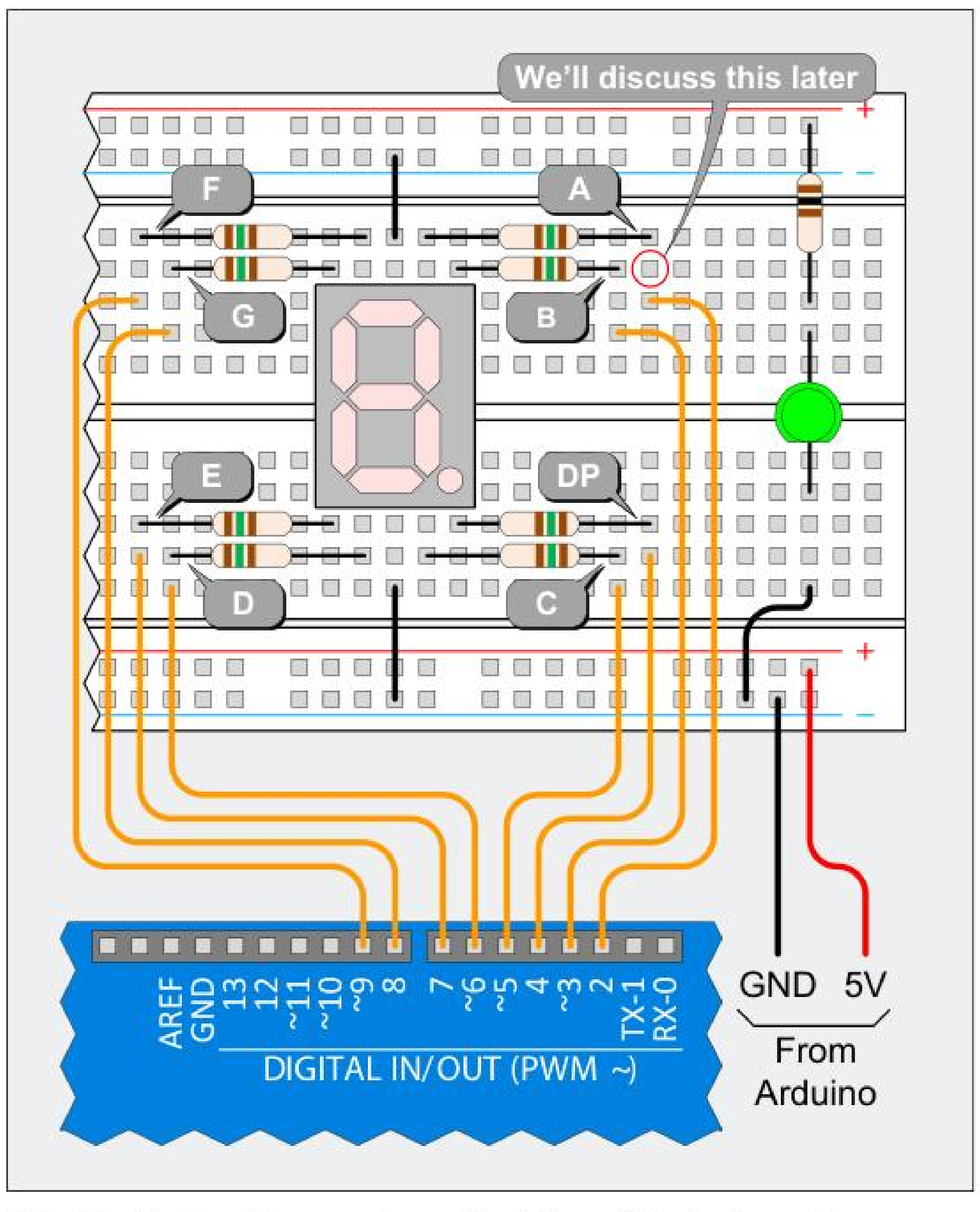


Fig.2. Actual layout and wiring (Arduino shown in blue).

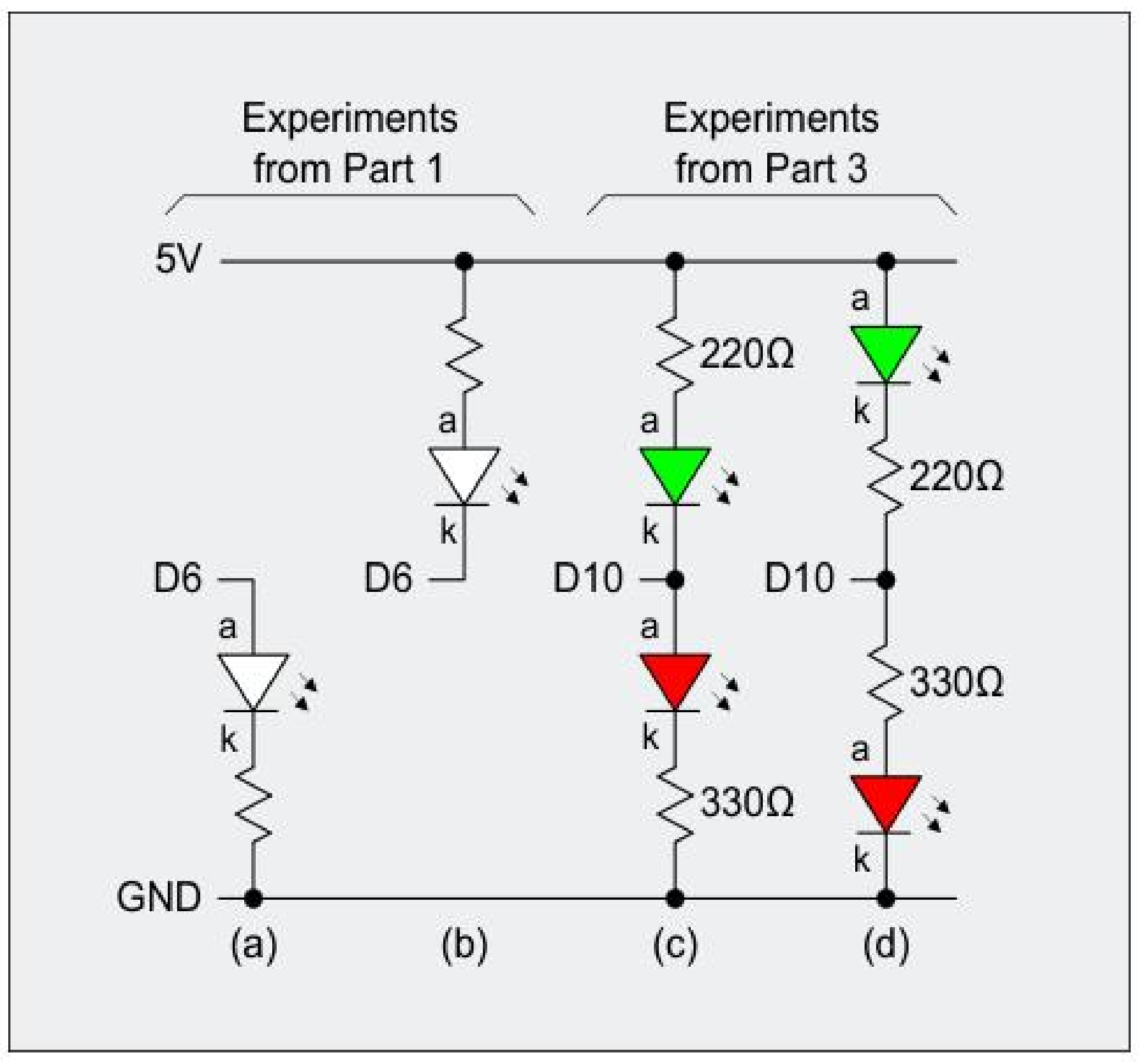


Fig.3. Experiments with individually packaged LEDs.

the resistance to 200Ω, thereby halving the current to 10mA. Unfortunately, the closest value I have in my variety pack of resistors is 220Ω (with colour bands of red-red-brown), but 'that's close enough for government work,' as they say.

You might wish to experiment further by gradually increasing or decreasing the resistor value until you achieve a brightness that pleases your eye (don't go lower than 100Ω, or you will end up with a dead LED). If you do decide to perform this experiment, remember to keep track of the results in your logbook.

In the case of our 7-segment display, since each of this display's red LEDs has a V_F of 2V and an I_F of 20mA, we decided to use 150Ω resistor values on its anode terminals (Fig.1). These resistors have brown-green-brown colour bands (Fig.2). Based on our discussions above, we could decide to double the values of these resistors to 300Ω. In this case, the closest value I have is 330Ω (with colour bands of orange-orange-brown).

We will use a 330Ω resistor with the individual red LED we are going to experiment with in a moment. In the case of our 7-segment display, however, for reasons that will be made clear in the fullness of time, we are going to stick with our existing 150Ω current-limiting resistors.

One LED (how sad)

Before we return to experimenting with our 7-segment display, let's take a little diversion that will help increase our understanding of what's happening inside the Arduino.

Remember that an LED will turn on and light up if its anode (a) terminal is at a more positive potential than its cathode (k) terminal (this assumes that the potential difference is greater than the LED's V_F value, of course).

In *Part 1*, we created our own version of the standard Arduino *Blink* program ('sketch' in the vernacular of the Arduino community). As part of this, we configured the Arduino's digital input/output (I/0) pin 6 to act as an output. We then used this output to drive the anode terminal of an LED whose cathode terminal was connected to GND (0V) via a current-limiting resistor (Fig.3a).

In the most current version of this program, we commence with three `#define` statements – you can access this program, file **CB-Mar23-01.txt**, and all the others mentioned here from the March 2023 page of the *PE* website at: **https://bit.ly/pe-downloads**

```
#define PIN_LED   6
#define LED_ON    HIGH
#define LED_OFF   LOW
```

Later, in the body of the program, we use these definitions in calls to the Arduino's `digitalWrite()` function to turn our LED on for 100ms and off for 900ms, thereby providing a 1/10th-second flash once each second.

```
// Turn the LED on
digitalWrite(PIN_LED, LED_ON);
delay(100);

// Turn the LED off
digitalWrite(PIN_LED, LED_OFF);
delay(900);
```

When we compile our source code into the machine code that will run on the Arduino, the preprocessor will replace any instances of `PIN_LED`, `LED_ON`, and `LED_OFF` with `6`, `HIGH`, and `LOW`, respectively. In the case of an Arduino Uno, when they are presented to the outside world, `HIGH` equates to 5V and `LOW` equates to 0V.

In a variation of this experiment, we used the same output to drive the cathode terminal of an LED whose anode terminal was connected to 5V via a current-limiting resistor (Fig.3b). As part of this, we modified our `LED_ON` and `LED_OFF` definitions as follows (file **CB-Mar23-02.txt**):

```
#define LED_ON   LOW
#define LED_OFF HIGH
```

Had we not performed this modification, instead sticking with our original version of the program, then the LED in Fig.3b would have been on for 9/10th of a second and off for 1/10th of a second.

Two LEDs (twice the fun)

Now look at Fig.3c. In this case, we have a green LED whose anode is connected to 5V via its current-limiting resistor. We also have a red LED whose cathode is connected to 0V via its current-limiting resistor. Observe that, in this case, we are using our new 220Ω and 330Ω resistor values as discussed earlier in this column.

The green LED's cathode is connected to the red LED's anode, and this point is also connected to the Arduino's digital I/O pin 10. The reason we are using pin 10 in this case is that we're already using pins 2 through 9 to drive our 7-segment display.

So, what do you think will happen if the Arduino drives a `LOW` or a `HIGH` on pin 10. While you are pondering this question, let's take a moment to note that the circuit in Fig.3d is functionally equivalent to that in Fig.3c. The only reason for showing Fig.3d is to remind ourselves that (in a series circuit) the ordering of an LED and its current-limiting resistor doesn't matter.

Returning to our question. If there's a `LOW` (0V) on pin 10, then the green LED will have 5V on its anode and 0V on its cathode, so it will start conducting and light up. Meanwhile, the red LED will have 0V on both its anode and cathode, which means it will do nothing at all.

Contrariwise, if the Arduino drives a `HIGH` (5V) on pin 10, then the green LED will have 5V on its anode and 5V on its cathode, which means it won't do anything. By comparison, the red LED will have 5V on its anode and 0V on its cathode, which means it will start conducting and light up.

Unplug the USB cable from your Arduino, and then implement the circuit from Fig.3c in an unused area of your breadboard. However, in the case of the jumper wire connected to the centre point between the two LEDs, let's not connect that to pin 10 on the Arduino just yet. Instead, let's leave it as a flying lead (Fig.4).

The reason for keeping this as a flying lead is because – as we discussed in *Part 2* – we can make our lives a lot easier by making sure our hardware is working as planned before we start trying to drive it with our software.

Once you've wired this circuit up, plug the USB cable back into the Arduino. Once again, our original green LED will light up and we will see the random lighting of the segments on the 7-segment display. In the case of our two new LEDs, since their combined forward-voltage drop as specified in their data sheets is 5V (3V for the green LED plus 2V for the red LED), these LEDs should both be turned off. In the real world, however, their forward voltage drops may be

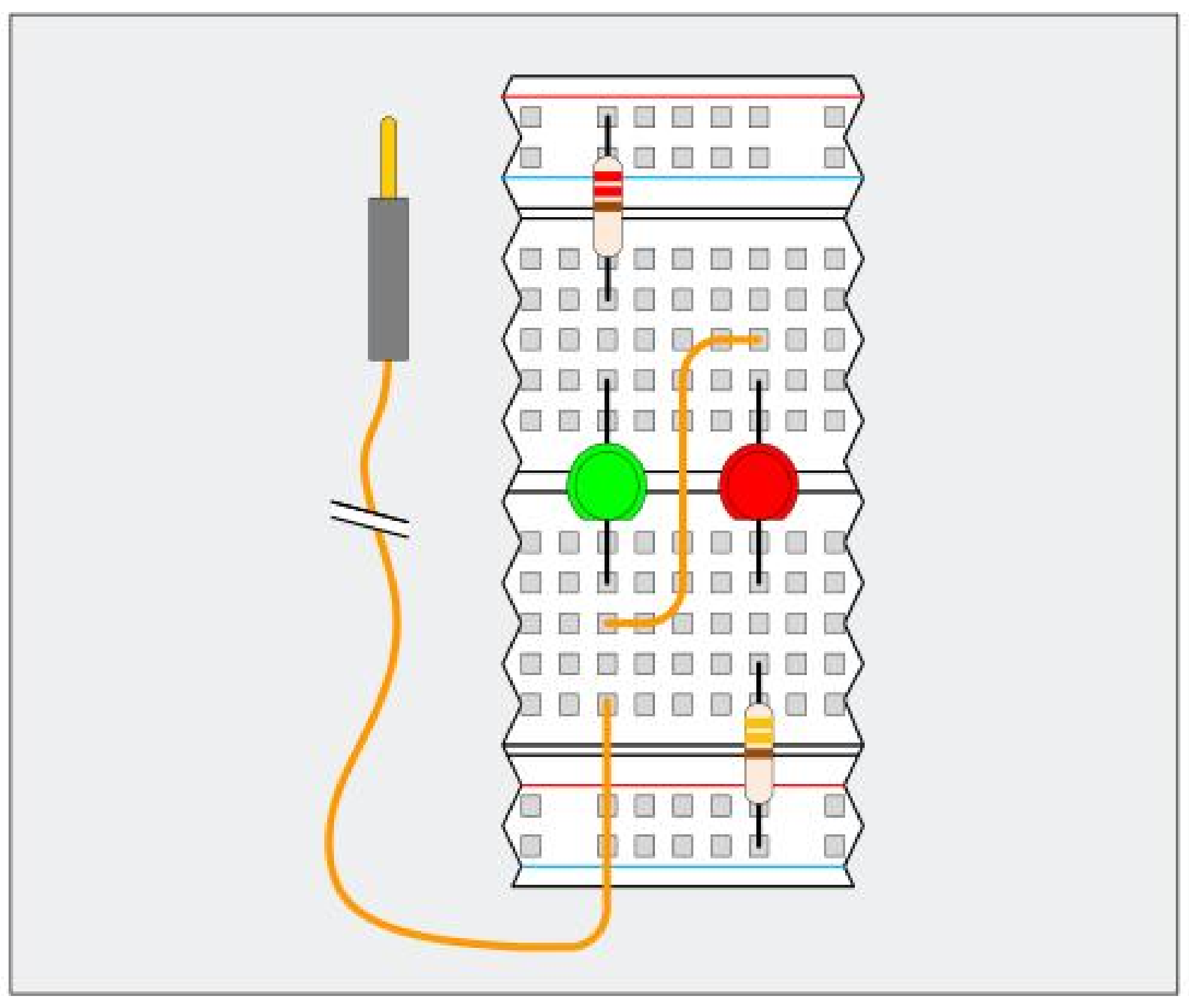
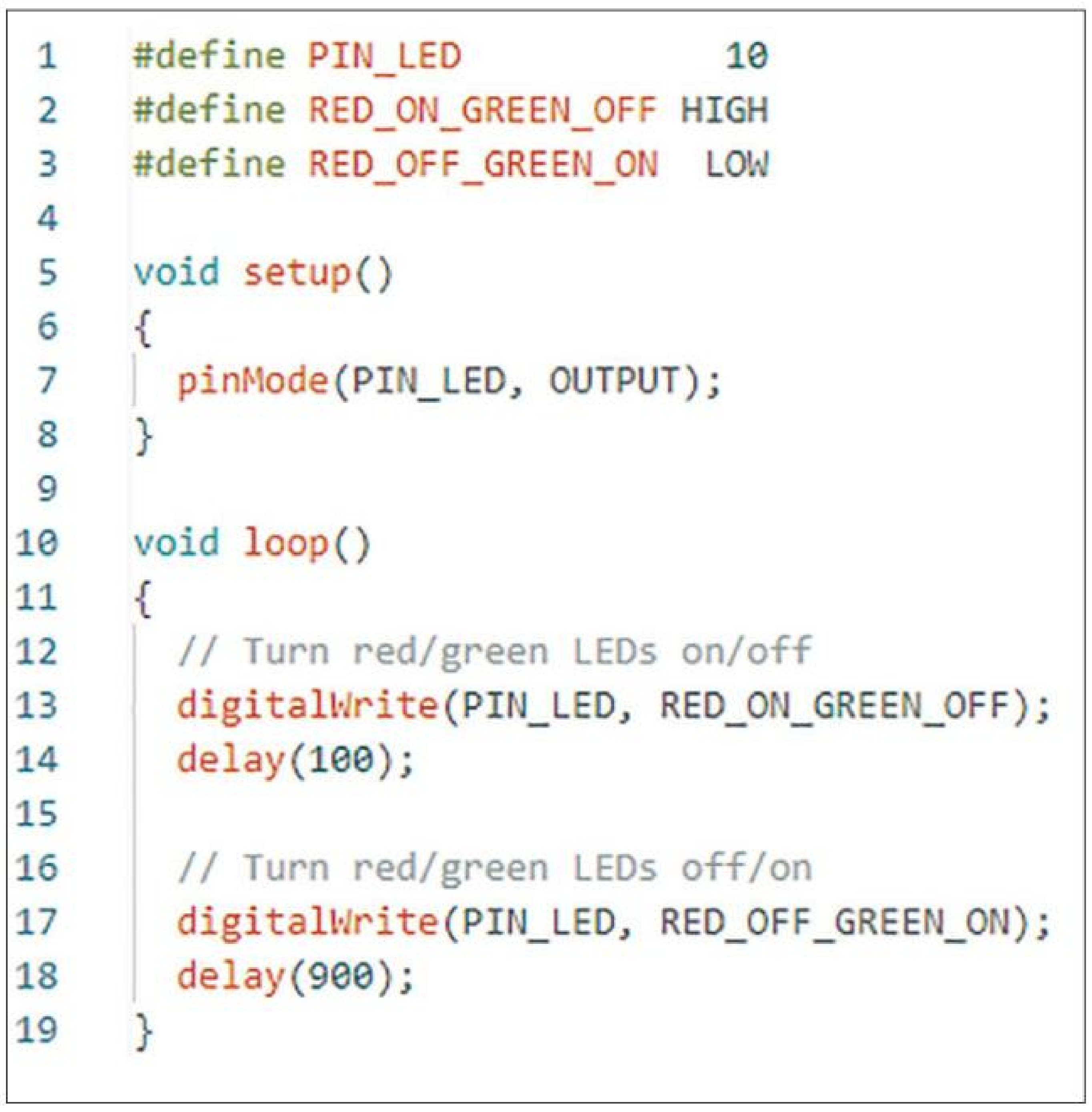


Fig.4. Two LEDs is twice the fun.



```
#define PIN_LED           10
#define RED_ON_GREEN_OFF HIGH
#define RED_OFF_GREEN_ON  LOW

void setup()
{
  pinMode(PIN_LED, OUTPUT);
}

void loop()
{
  // Turn red/green LEDs on/off
  digitalWrite(PIN_LED, RED_ON_GREEN_OFF);
  delay(100);

  // Turn red/green LEDs off/on
  digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
  delay(900);
}
```

Listing 1. Using definitions more suited to our red/green LED combo.

less than stated on their datasheets, in which case both LEDs may light up to some extent.

If you plug the free end of the flying lead into one of the holes on the breadboard's 5V rail (the one with the red line), the green LED should turn off and the red LED should light up. If you now unplug the flying lead from the 5V rail and plug it into one of the holes on the breadboard's 0V rail (the one with the blue line), the green LED should light up and the red LED should turn off.

Just for giggles and grins, unplug the flying lead from the breadboard's 0V rail and plug it into the hole indicated by the red circle in Fig.2 (the one annotated with the words 'We'll discuss this later'). Observe that our new red LED will now flash in time with the 'A' segment on our 7-segment display (the new green LED will be in the opposite state to the red LED). Congratulations! You've just created a basic logic probe – see: **https://bit.ly/3YJbIl6**

HIGH or LOW?

Now, unplug the flying lead from the 0V rail and connect it to pin 10 on the Arduino. At this time, as discussed above, both of our new LEDs should either be off (if their combined forward voltage drops are greater than or equal to 5V) or dimly illuminated (if their combined voltage drops are less than 5V).

This is what we've been seeing when the end of our flying lead isn't connected to anything, but we just connected it to pin 10 on our Arduino. What gives? Well, as we discussed in *Part 1*, when a microcontroller is first powered up, all its pins are set to be inputs by default. This means that, as far as what used to be our 'flying lead' is concerned, it's not currently being driven by anything, which is the same as it not being connected to anything.

Let's create an updated version of our early Blink program to drive our red-green LED combo. In the past, we associated definitions of `LED_ON` and `LED_OFF` with `HIGH` and `LOW` (or `LOW` and `HIGH`) respectively, but these definitions no longer cut the mustard, as it were. We need to employ more meaningful definitions, as shown in Listing 1 (see also file **CB-Mar23-03.txt**).

Observe that we've changed our `PIN_LED` definition to be associated with pin 10 on the Arduino. Also, we are now associating `RED_ON_GREEN_OFF` and `RED_OFF_GREEN_ON` with `HIGH` and `LOW`, respectively. Although our new definitions are a tad more verbose (perhaps 'robust' would be a better word), they make it easy for people to understand the tasks this program is intended to accomplish.

Use the Arduino's IDE to capture this code, click the Verify icon (or use the Sketch > Verify/Compile command) to make sure things are as they should be, then click the Upload icon (or use the Sketch > Upload command) to upload the resulting machine code into the Arduino and feast your orbs on your flashing LEDs.

Layers of abstraction

I don't know about you, but I always like to have an idea as to what's going on 'under the bonnet' as we say in the UK (or 'under the hood' in the vernacular of the US). There's a huge amount to wrap our brains around here, but a racing version is as follows.

It's common to hear computer boffins say that digital computers like our Arduino microcontroller are based on 0s and 1s ('zeros and ones'), but what does this really mean? Well, at the interface where the microcontroller meets the real world in the form of its digital I/O pins, we are working with real voltages, such as 0V and 5V in the case of an Arduino Uno.

Everything else is an abstraction intended to make our lives easier. For example, we use 0 and 1 as abstractions for 0V and 5V, respectively. Similarly, we use `LOW` and `HIGH` as abstractions of 0 and 1, and we use definitions like `RED_OFF_GREEN_ON` and `RED_ON_GREEN_OFF` as abstractions of `LOW` and `HIGH`.

But why do we use 0 and 1 in the first place? Well, let's start with the fact that a digital quantity is one that can be represented as being in one of a finite number of states. The simplest digital systems employ only two states, which we might refer to as 0 and 1, UP and DOWN, IN and OUT, OFF and ON, and so on.

Next, let's note that sometime around the 1850s, a British mathematician called George Boole established a new mathematical field known as symbolic logic, which we now know as Boolean algebra. Unfortunately, outside mathematical circles, no one really cared.

In the early part of the 20th century, inventors started to create electrical circuits based on switching elements that could perform simple arithmetic functions and/or execute sequences of operations to control things like industrial machinery. These switching elements included regular switches, electromagnetic switches in the form of relays, and electronic switches in the form of vacuum tubes. However, there was a limit to the complexity of the systems those inventors could achieve because they didn't have appropriate mathematical tools at their disposal.

In the late 1930s, a graduate student at MIT called Claude Shannon submitted a master's thesis that revolutionised electronics. In this thesis, Shannon showed that Boolean algebra offered an ideal technique for representing the logical operation of digital systems. Shannon had realised that the Boolean concepts of *false* and *true* could be mapped onto the binary digits 0 and 1, and that both could be easily implemented by means of electronic circuits.

Most materials are conductors, insulators, or something in-between. A special class of materials called 'semiconductors' can be persuaded to exhibit both conducting and insulating properties; silicon is one such material. The first transistor was made in 1947 from another semiconductor material called 'germanium' and these were made commercially available in the early 1950s. In the case of digital computers, we think of transistors as acting like switches. Today's transistors can be very small (we can build billions of them on a silicon chip) and very fast (they can be activated and deactivated billions of times a second). Also, the output from one transistor can drive the inputs of other transistors.

We can connect small groups of transistors together to form simple logical building blocks that can detect the difference between two voltage values and can present the results of their operations in terms of these voltages. These simple building blocks can be connected to create larger logical functions, which can themselves be connected to realise sophisticated systems such as digital computers. Rather than think in terms of two actual voltages, we prefer to abstract things and talk in terms of 0s and 1s.

When we write a program for an Arduino, we can make use of built-in functions like `digitalWrite()`, which writes a value to one of the Arduino's digital input/output (I/O) pins. This function

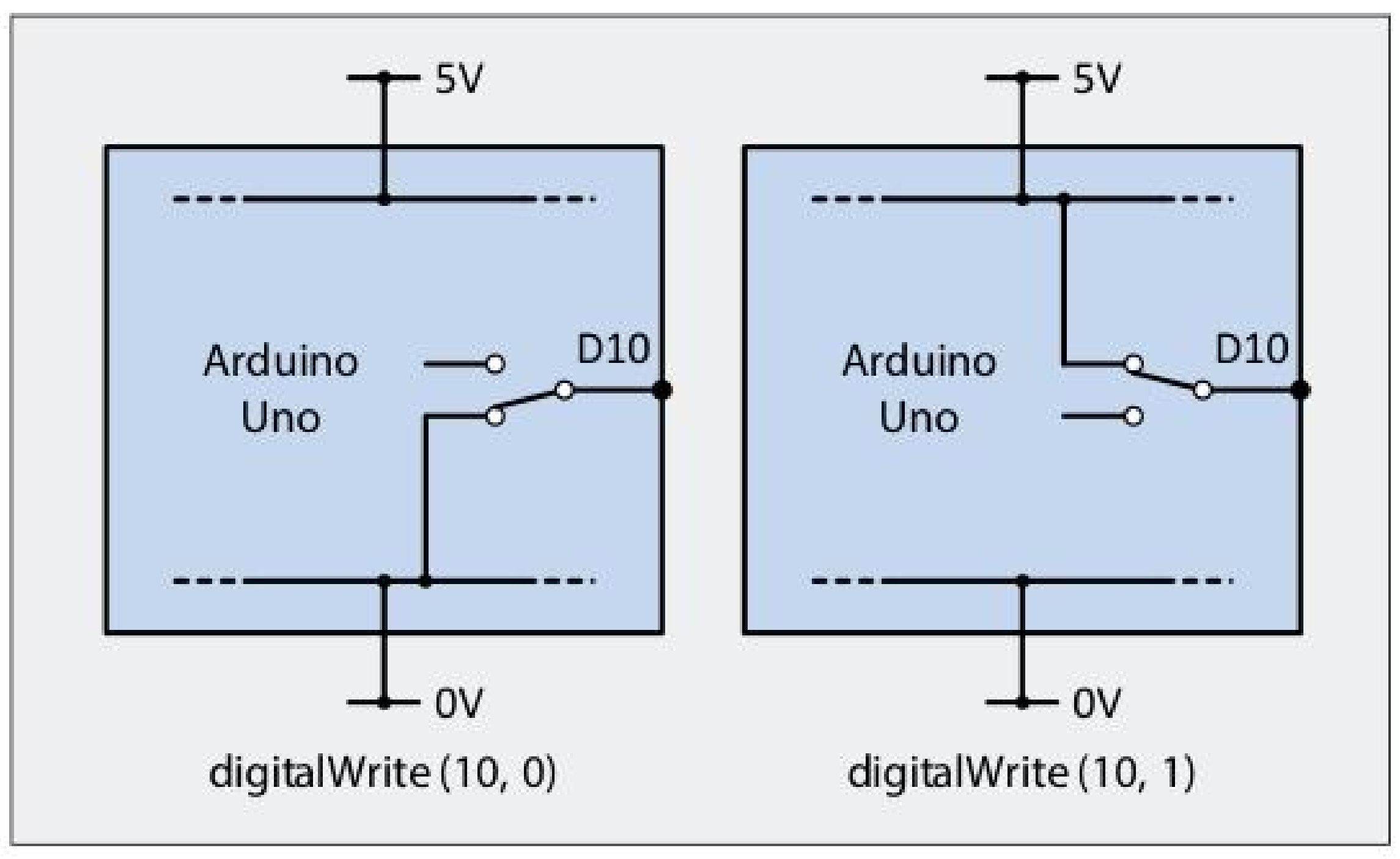


Fig.5. Visualising how the `digitalWrite()` function performs its magic.

accepts two integer arguments (think parameters): the first is the number of the pin we wish to control and the second is the value we wish to output, where this value can be a 0 or a 1. If we wanted to write 0 or 1 values to pin 10, for example, we could do so as follows:

```
digitalWrite(10,0);
digitalWrite(10,1);
```

As we've already discussed, these 0 and 1 values will appear on the Arduino Uno's pin as 0V and 5V, respectively. One way to visualise how this works is illustrated in Fig.5.

In the same way, we can make a single transistor behave like a simple switch, we can use a couple of transistors to implement the equivalent of a single-pole, double-throw (SPDT) switch. By means of our `digitalWrite()` commands, we can cause this switch to connect the output pin to the 0V or 5V rails inside the Arduino, thereby presenting these values to the outside world.

The creators of the Arduino decided that, rather than use 0 and 1, it would be easier for beginners to work with the keywords `LOW` and `HIGH`. The only problem is that the C/C++ programming languages used by the Arduino's integrated development environment (IDE) don't support these keywords.

Based on what we've already learned, we could define these keywords ourselves as follows:

```
#define LOW 0
#define HIGH 1
```

Although they decided to employ a slightly different approach, this is essentially what the folks who set up the Arduino IDE did behind the scenes.

If you are interested in learning more about all of this, I've penned and posted a frankly fulsome column for your delectation and delight – see: **https://bit.ly/3GacoZv**

True or false?

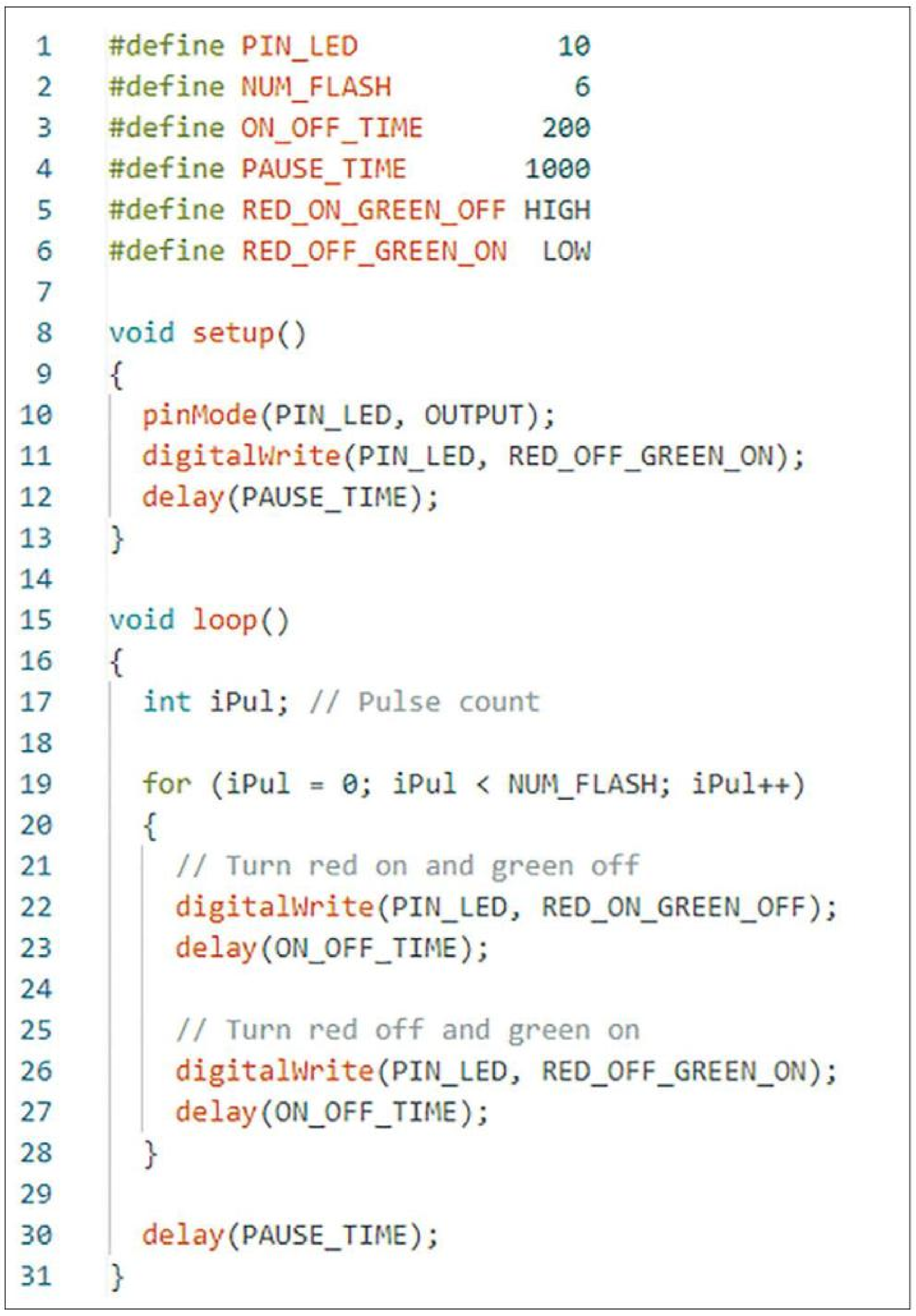
As we previously noted, the Arduino IDE supports a combination of the C/C++ programming languages. Some computer languages support the `bool` and/or `boolean` data types, which are used to represent the Boolean concepts of *false* and *true*. Unfortunately, C doesn't natively support either of these types (sad face). Fortunately, C++ does support the `bool` data type (happy face). And, just to add to the fun and frivolity, the Arduino IDE supports both types.

A variable of type `bool` (or `boolean`) can be assigned values of `true` and `false`. We will be running into these values a lot in the not-so-distant future. Before we do, however, it's worth noting that the `bool` data type is essentially an alias of the `int` (integer) data type that's restricted to having values of 0 (`false`) and 1 (`true`). Furthermore, the `boolean` data type is essentially an alias of the `bool` data type.

Once again, based on what we've already learned, we could define these keywords ourselves as follows:

```
#define false 0
#define true  1
```

And, once again, although they decided to employ a slightly different approach, this is essentially what the folks who set up the Arduino IDE did behind the scenes.



```
#define PIN_LED           10
#define NUM_FLASH          6
#define ON_OFF_TIME      200
#define PAUSE_TIME      1000
#define RED_ON_GREEN_OFF HIGH
#define RED_OFF_GREEN_ON  LOW

void setup()
{
  pinMode(PIN_LED, OUTPUT);
  digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
  delay(PAUSE_TIME);
}

void loop()
{
  int iPul; // Pulse count

  for (iPul = 0; iPul < NUM_FLASH; iPul++)
  {
    // Turn red on and green off
    digitalWrite(PIN_LED, RED_ON_GREEN_OFF);
    delay(ON_OFF_TIME);

    // Turn red off and green on
    digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
    delay(ON_OFF_TIME);
  }

  delay(PAUSE_TIME);
}
```

Listing 2. Using a `for()` loop to pulse the LEDs 6 times.

As we will come to realise, this opens the door to a wide range of possibilities. For example, if we wish to write a 0 to pin 6, we could do so using:

```
digitalWrite(6, false);
```

Alternatively, if we wish to write a 1 to pin 6, we could do so using:

```
digitalWrite(6, true);
```

Similarly, if we declare a variable as being of type `bool` (or `boolean`), in addition to assigning it values of `false` and `true`, we can also assign it values of 0 and 1 and `LOW` and `HIGH`.

For() better or worse

There are three types of loop control statements in C/C++. These statements can be used to perform the same group of actions multiple times. One of them is the `for()` statement, which we introduced in *Part 2*. Just to remind ourselves, the general form of this statement is as follows:

```
for (initialize; condition; update)
{
  // Do stuff
}
```

Suppose we wish to quickly pulse (flash) our red-green LED combo six times, wait a second, and then do it all again. We could achieve this using a `for()` statement as illustrated in Listing 2 (see also file **CB-Mar23-04.txt**).

We won't go through this code in detail because we've seen variations of all these statements before. However, one point worth noting is that, in this example, we've declared our loop control variable, `iPul`, outside the `for()`

statement. As you may recall, my preference is to declare this as part of the `for()` statement as shown in red below:

```
for (int iPul = 0; ...
```

The rationale for declaring this variable as part of the `for()` statement is this limits the scope (ie, the visible range) of the variable to the loop. And the reason for our declaring it outside the `for()` statement in this example is that it will help us wrap our brains around what's happening when we compare what we are doing here with the other loop control statements, which we will look at in a moment.

It's the condition portion of the `for()` statement that's of interest to us here. In this case, we used `iPul < NUM_FLASH` (that is, '`iPul` is less than `NUM_FLASH`'), where we previously defined `NUM_FLASH` ('the number of flashes') as being 6. This condition will evaluate to a Boolean value of `true` (if `iPul` is indeed less than `NUM_FLASH`) or false (if `iPul` is greater than or equal to `NUM_FLASH`). The body of the loop will be executed so long as the condition returns `true`, and the loop will be terminated as soon as the condition returns `false`.

In this case, our loop will execute six times for `iPul` = 0, 1, 2, 3, 4, and 5, and it will terminate as soon as `iPul` reaches 6.

Enter this program into your Arduino IDE and click the Verify icon to check you haven't made any mistakes. Next, click the Upload icon to upload the machine code version of this program into your Arduino and count the number of flashes to check that all is as we expect.

As a point of interest, try changing your `for()` loop's initialise statement to `int iPul = 1` and its condition statement to `iPul <= NUM_PULSES` (that is, '`iPul` is less than or equal to `NUM_FLASH`'). In this case, our loop will execute six times for `iPul` = 1, 2, 3, 4, 5, and 6, and it will terminate as soon as `iPul` reaches 7.

While() we're here

In addition to the `for()`, there are two more loop control statements in C/C++. The first is the `while()`, in which a condition is checked *before* executing the body of the loop. Once again, the body of the loop will only be executed if the condition returns a Boolean value of `true`, otherwise the loop will be terminated.

```
while (someCondition)
{
  // Do stuff
}
```

The second is the `do-while()` in which a condition is checked *after* executing the body of the loop. In this case, the body of the loop will always be executed at least one time, after which it will continue to be executed only so long as the condition returns `true`.

```
do
{
  // Do stuff
} while (someCondition);
```

Let's create, contrast, and compare two programs using these different approaches to flash our red-green LED combo six times, as shown in Listing 3 (see also files **CB-Mar23-05.txt** and **CB-Mar23-06.txt**).

In both of these examples, we increment the loop counter `iPul` at the end of the loop (previously, we did this as the update portion of the `for()` statement itself). Remember that `iPul++` is the same as saying `iPul = iPul + 1`.

With respect to the examples shown here, there doesn't really seem to be much to choose between these loop control forms.

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However, sometimes it is critical to evaluate the condition prior to executing the loop, in which case we could choose to use the `while()` loop. On other occasions, as we will soon see, it is advantageous to execute the loop before evaluating the condition, in which case the `do-while()` is the way to go.

There's a condition

Thus far, we've considered only simple conditions involving the relational operators `<` ('less than') and `<=` ('less than or equal to'). There are two more relational operators, `>` ('greater than') and `>=` ('greater than or equal to'). Also, there are two equality operators, `==` ('equal to') and `!=` ('not equal to').

Furthermore, we can create more complex expressions using the `&&` ('logical AND') and `||` ('logical OR') operators. For example, assume that `a`, `b`, `c` and `d` have all been declared as being of type `int` and assigned values, we could have a condition looking something like the following:

```
(a > b) && (c <= d)
```

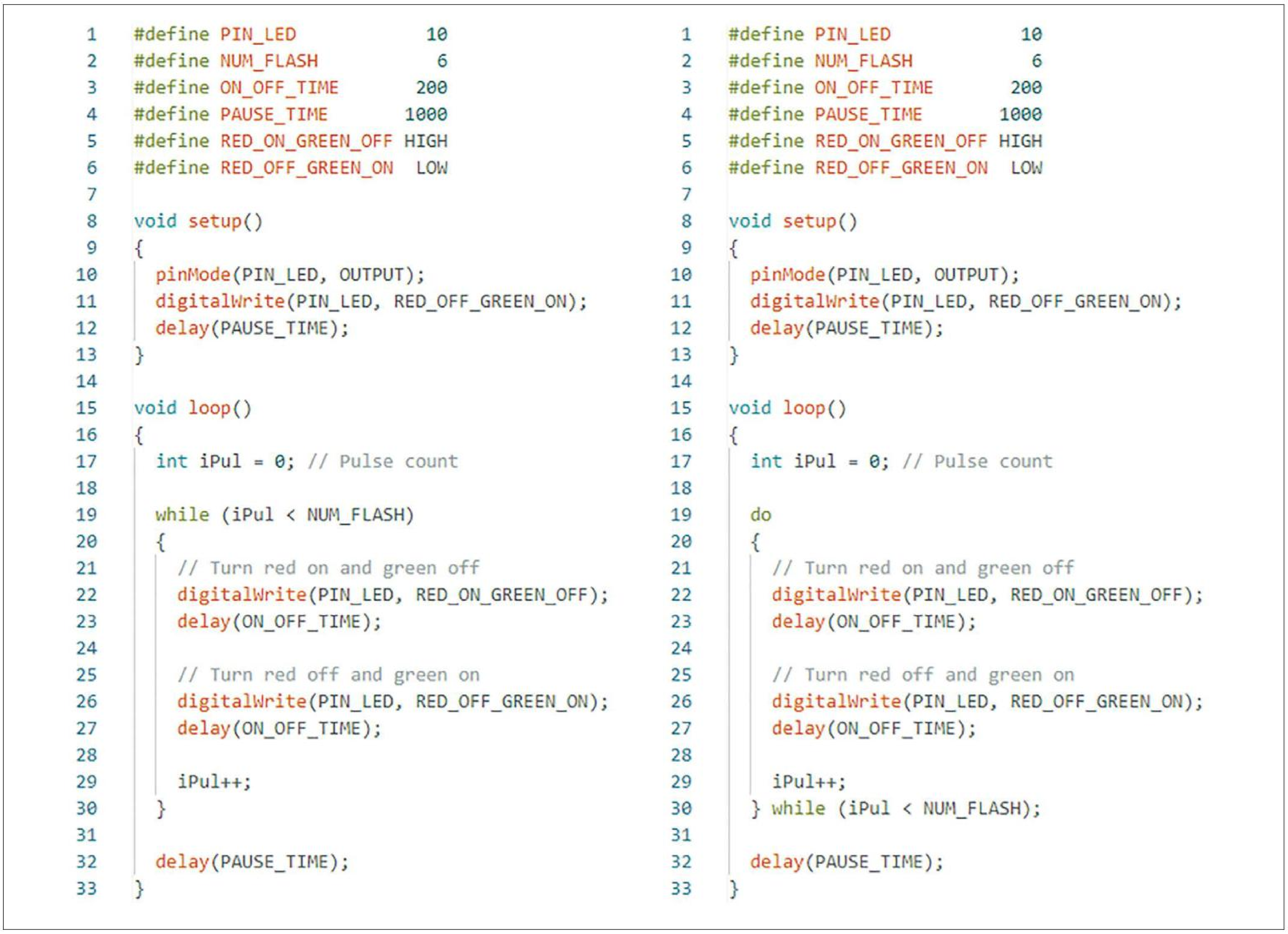
This condition will return `true` only if `a` is greater than `b` AND `c` is less than or equal to `d`, otherwise it will return `false`. All of the operators mentioned here are summarised in Fig.6.

Who takes precedence?

When we were kids studying math at school, we were taught the convention that multiplication and division are performed before addition and subtraction. This means, for example, that we evaluate the result of the expression 2 + 2 × 3 as being 8 rather than 12. We say that the multiplication and division operators have 'higher precedence' than the addition and subtraction operators.

If we wanted to, we could emphasise the conventional precedence in the preceding calculation using parentheses, eg, 2 + (2 × 3). Alternatively, we could force a different precedence, eg, (2 + 2) × 3.

Similarly, in the context of computer programming languages like C/C++, the term 'precedence of operators' refers



```
#define PIN_LED           10
#define NUM_FLASH          6
#define ON_OFF_TIME      200
#define PAUSE_TIME      1000
#define RED_ON_GREEN_OFF HIGH
#define RED_OFF_GREEN_ON  LOW

void setup()
{
  pinMode(PIN_LED, OUTPUT);
  digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
  delay(PAUSE_TIME);
}

void loop()
{
  int iPul = 0; // Pulse count

  while (iPul < NUM_FLASH)
  {
    // Turn red on and green off
    digitalWrite(PIN_LED, RED_ON_GREEN_OFF);
    delay(ON_OFF_TIME);

    // Turn red off and green on
    digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
    delay(ON_OFF_TIME);

    iPul++;
  }

  delay(PAUSE_TIME);
}
```

```
#define PIN_LED           10
#define NUM_FLASH          6
#define ON_OFF_TIME      200
#define PAUSE_TIME      1000
#define RED_ON_GREEN_OFF HIGH
#define RED_OFF_GREEN_ON  LOW

void setup()
{
  pinMode(PIN_LED, OUTPUT);
  digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
  delay(PAUSE_TIME);
}

void loop()
{
  int iPul = 0; // Pulse count

  do
  {
    // Turn red on and green off
    digitalWrite(PIN_LED, RED_ON_GREEN_OFF);
    delay(ON_OFF_TIME);

    // Turn red off and green on
    digitalWrite(PIN_LED, RED_OFF_GREEN_ON);
    delay(ON_OFF_TIME);

    iPul++;
  } while (iPul < NUM_FLASH);

  delay(PAUSE_TIME);
}
```

Listing 3. Using `while()` and `do-while()` loops to pulse the LEDs 6 times: (left) `while()` loop; (right) `do-while()` loop.

to the order in which operations are performed. For example, the multiplication, division, and modulo operators (`*`, `/`, and `%`) have higher precedence than the addition and subtraction operators (+ and –), and all of these arithmetic operators have higher precedence than the relational, equality, and logical operators discussed above.

Well, that all seems pretty simple, doesn't it? So, assuming once again that `a`, `b`, `c` and `d` have all been declared as being of type `int` and assigned values, how would you expect the condition `a + 6 > b / 2 && c * 3 < d – 5` to be evaluated?

Suffice it to say that many a programmer (both inexperienced and experienced) has been bitten by an unexpected precedence problem. For myself, I prefer to employ copious quantities of parentheses to make clear to future users and to the compiler just what I wish to occur, which means I would capture the aforementioned condition as `((a + 6) > (b / 2)) && ((c * 3) < (d – 5))` (you can call me an old fuddy-duddy if you will, but at least my code works as planned).

If you wish to learn more about this topic, you'll be delighted to discover that it is documented in excruciating detail on Wikipedia at: **https://bit.ly/3GdcG1M**

Type	Operator	Description	Example
Relational	`<`	Less than	`a < b`
	`<=`	Less than or equal to	`a <= b`
	`>`	Greater than	`a > b`
	`>=`	Greater than or equal to	`b >= b`
Equality	`==`	Equal to	`a == b`
	`!=`	Not equal to	`a != b`
Logical	`&&`	Logical AND	`a && b`
	`||`	Logical OR	`a || b`

Fig.6. Table of Boolean operators available in C/C++ for use with the Arduino.

A long pause

Now it's time to put some of the things we've learned in this column to use with our 7-segment display. As you may recall, the final program we created in our previous column randomly lit the segments on the display. The original version of this program is shown in Listing 4a (file **CB-Mar23-07.txt**). As you'll see, I've added a few blank lines to aid in our comparison with an updated version of the program, as reflected in Listing 4b (file **CB-Mar23-08.txt**).

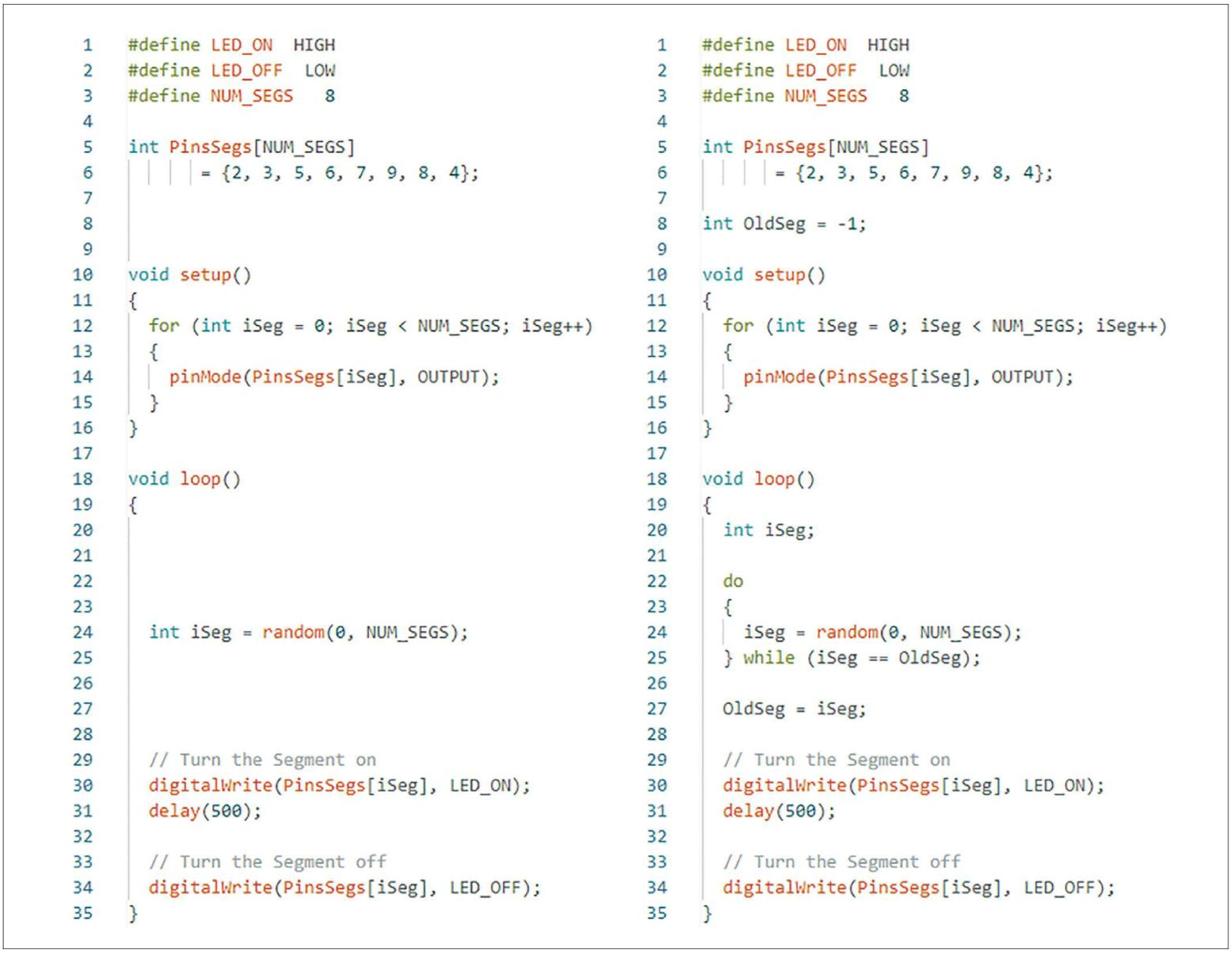
Let's start with our original program. As a reminder, the Arduino pins used to drive our segments are defined in the `PinsSegs[]` array on Lines 5 and 6. There are eight elements in this array, numbered from 0 to 7. This is why we generate a random number with a value between 0 and 7 on Line 24.

Upload the original program into your Arduino and carefully observe what happens on the 7-segment display. As promised, all eight segments (including the decimal point) light up in a random fashion. If we look closely, however, we will see that some of the segments randomly stay lit longer than others.

The reason for this is that, when we generate a random number on Line 24, we don't check to see if this new number is different to the previous number. If the values are the same, then the current segment will remain lit longer than if the values are different. What we want to do is force the values to be different.

Now consider the new version of the program in Listing 4b. The first change occurs on Line 8 where we declare an integer variable called `OldSeg` ('old segment') and assign it a value of –1.

Observe that, since `OldSeg` is declared outside of any of the functions, it is a global variable whose scope is the whole program. This means it can be seen and modified by any of the functions. It also means that whatever value it contains will be retained irrespective of which function is being executed (or not, as the case might be) at any particular time. Furthermore, as was noted in the previous column, my personal preference is to use initial uppercase letters to indicate global variables and initial lowercase letters to reflect local variables.



```
1   #define LED_ON   HIGH
2   #define LED_OFF   LOW
3   #define NUM_SEGS    8
4
5   int PinsSegs[NUM_SEGS]
6           = {2, 3, 5, 6, 7, 9, 8, 4};
7
8
9
10  void setup()
11  {
12    for (int iSeg = 0; iSeg < NUM_SEGS; iSeg++)
13    {
14      pinMode(PinsSegs[iSeg], OUTPUT);
15    }
16  }
17
18  void loop()
19  {
20
21
22
23
24    int iSeg = random(0, NUM_SEGS);
25
26
27
28
29    // Turn the Segment on
30    digitalWrite(PinsSegs[iSeg], LED_ON);
31    delay(500);
32
33    // Turn the Segment off
34    digitalWrite(PinsSegs[iSeg], LED_OFF);
35  }
```

```
1   #define LED_ON   HIGH
2   #define LED_OFF   LOW
3   #define NUM_SEGS    8
4
5   int PinsSegs[NUM_SEGS]
6           = {2, 3, 5, 6, 7, 9, 8, 4};
7
8   int OldSeg = -1;
9
10  void setup()
11  {
12    for (int iSeg = 0; iSeg < NUM_SEGS; iSeg++)
13    {
14      pinMode(PinsSegs[iSeg], OUTPUT);
15    }
16  }
17
18  void loop()
19  {
20    int iSeg;
21
22    do
23    {
24      iSeg = random(0, NUM_SEGS);
25    } while (iSeg == OldSeg);
26
27    OldSeg = iSeg;
28
29    // Turn the Segment on
30    digitalWrite(PinsSegs[iSeg], LED_ON);
31    delay(500);
32
33    // Turn the Segment off
34    digitalWrite(PinsSegs[iSeg], LED_OFF);
35  }
```

Listing 4. Using a `do-while()` loop to ensure a different random number: (left) original program; (right) updated program.

Components (from Part 1)

LEDs (assorted colours)	**https://amzn.to/3E7VAQE**
Resistors (assorted values)	**https://amzn.to/3O4RvBt**
Solderless breadboard	**https://amzn.to/3O2L3e8**
Multicore jumper wires (male-male)	**https://amzn.to/3O4hnxk**

Components (from Part 2)

7-segment display(s)	**https://amzn.to/3Afm8yu**

The reason we assign `OldSeg` a value of –1 is because we know this is different to any of the random numbers we will be generating in the range 0 to 7. We could, of course, use any value other than 0 through 7, but –1 is a common choice in this sort of thing.

The cunning part comes in Lines 22 to 25 where we use a `do-while()` loop to control the generation of our random number. The way this loop is set up is that we will keep on generating new random numbers as long as the condition evaluates as `true`, which will be the case if the newly generated segment value stored in `iSeg` is the same as the old segment value stored in `OldSeg`. As soon as the new value is different (not equal) to the old value, this condition will return `false` and the loop will terminate.

As soon as we are out of the loop, basking in the confident glow of knowing we have a new segment that is different to the old one, we copy this new value into `OldSeg` in Line 27 for use the next time we wish to generate a new segment.

Upload this new version of the program into your Arduino and observe that all of the randomly selected segments now remain illuminated for the same amount of time.

What's next?

We closed last month's column by saying: 'What would be useful while we wait for *Part 3* is for you to think about what segments we need to activate to represent the digits 0 through 9. Have you been thinking about this? Good. Hold that thought because this is what we will be doing in *Part 4*.

Meanwhile, the answer to the question posed at the beginning of this column is that we can ask either of the guards: 'Which door will the other guard say is the one that will take us where we wish to go?' Both guards will respond with the same door, which is the one we *don't* want to use.

I was just wondering if it would be possible to represent this riddle and its possible outcomes in the form of a truth table, but I'm exhausted after writing this column, so I'll leave that to you (please feel free to email me with your solution).

Until next time, as always, I welcome your insightful comments, perspicacious questions, and sagacious suggestions.

Cool bean Max Maxfield (Hawaiian shirt, on the right) is emperor of all he surveys at **CliveMaxfield.com** – the go-to site for the latest and greatest in technological geekdom.

Comments or questions? Email Max at: **max@CliveMaxfield.com**

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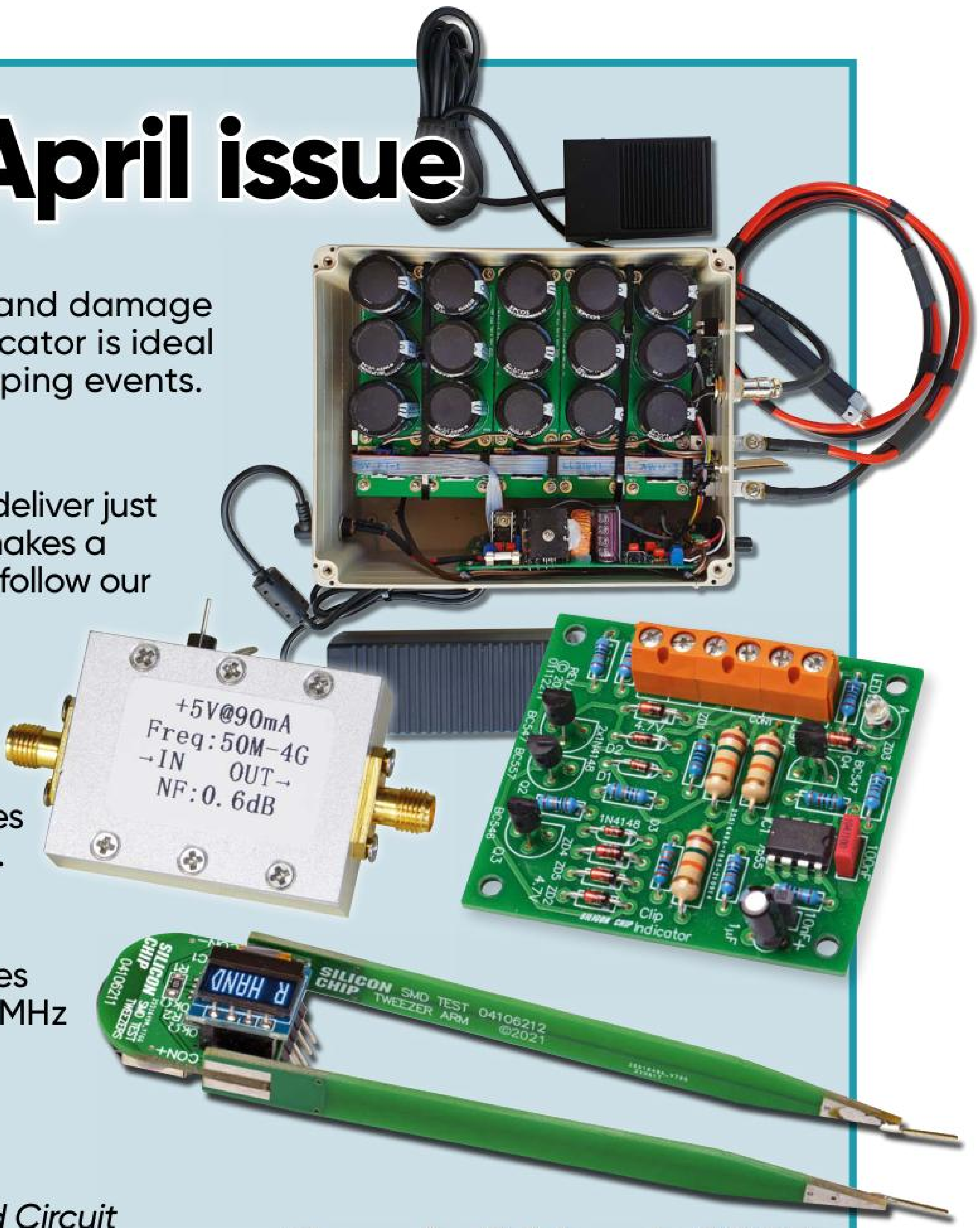
Next Month – in the April issue



Amplifier Clipping Indicator

Driving amplifiers into clipping can cause unpleasant sounds and damage expensive speakers. This easy-to-build Amplifier Clipping Indicator is ideal for showing clipping – its LED catches even the briefest of clipping events.

Capacitor Discharge Welder – Part 2

This Capacitor Discharge Welder has been carefully designed to deliver just the right amount of weld energy each time. When completed, it makes a neat package that's easy to build and safe to use, so long as you follow our advice. Having described how it works, we'll get into making it.

Improved SMD Test Tweezers

Our SMD Test Tweezers project from the October 2022 issue has been extremely popular. They are handy, compact, easy to use, easy to build and inexpensive. So, we decided to see what features we could add simply by upgrading the microcontroller at its heart.

Three Low-Noise HF-UHF Amplifiers

We'll look at three low-cost wideband HF-UHF amplifier modules offering 20dB of gain over frequency ranges of 1MHz to 3GHz, 5MHz to 6GHz and 50MHz to 4GHz.

PLUS!

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Content may be subject to change

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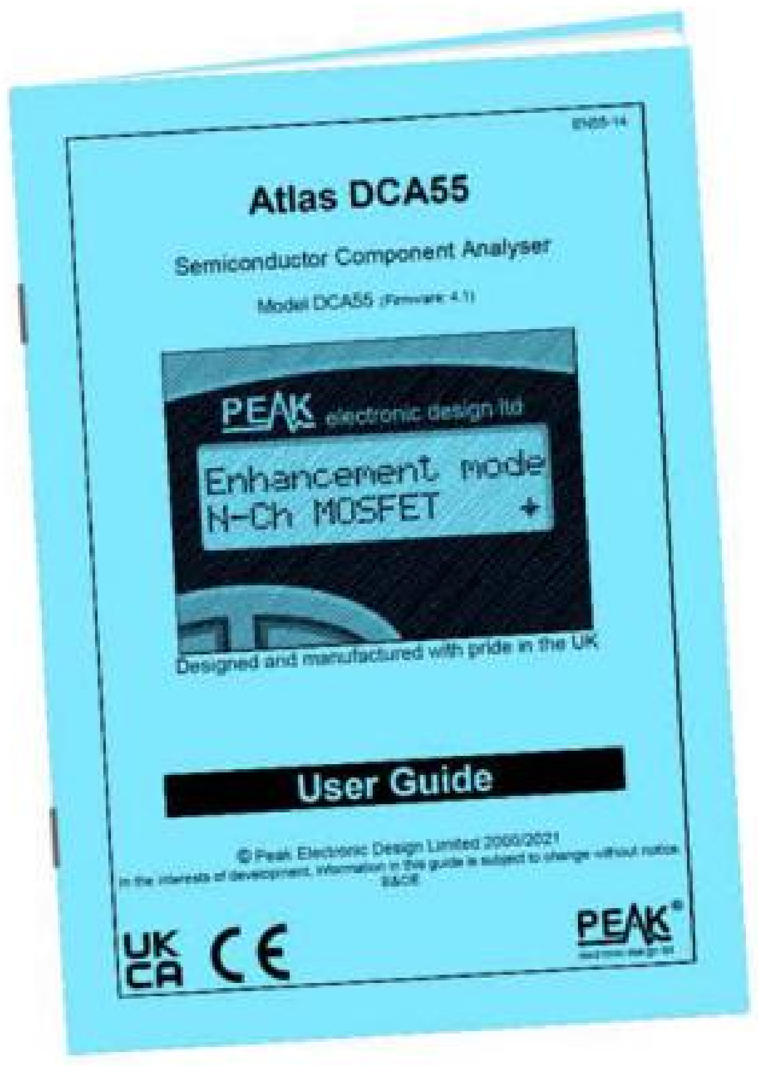

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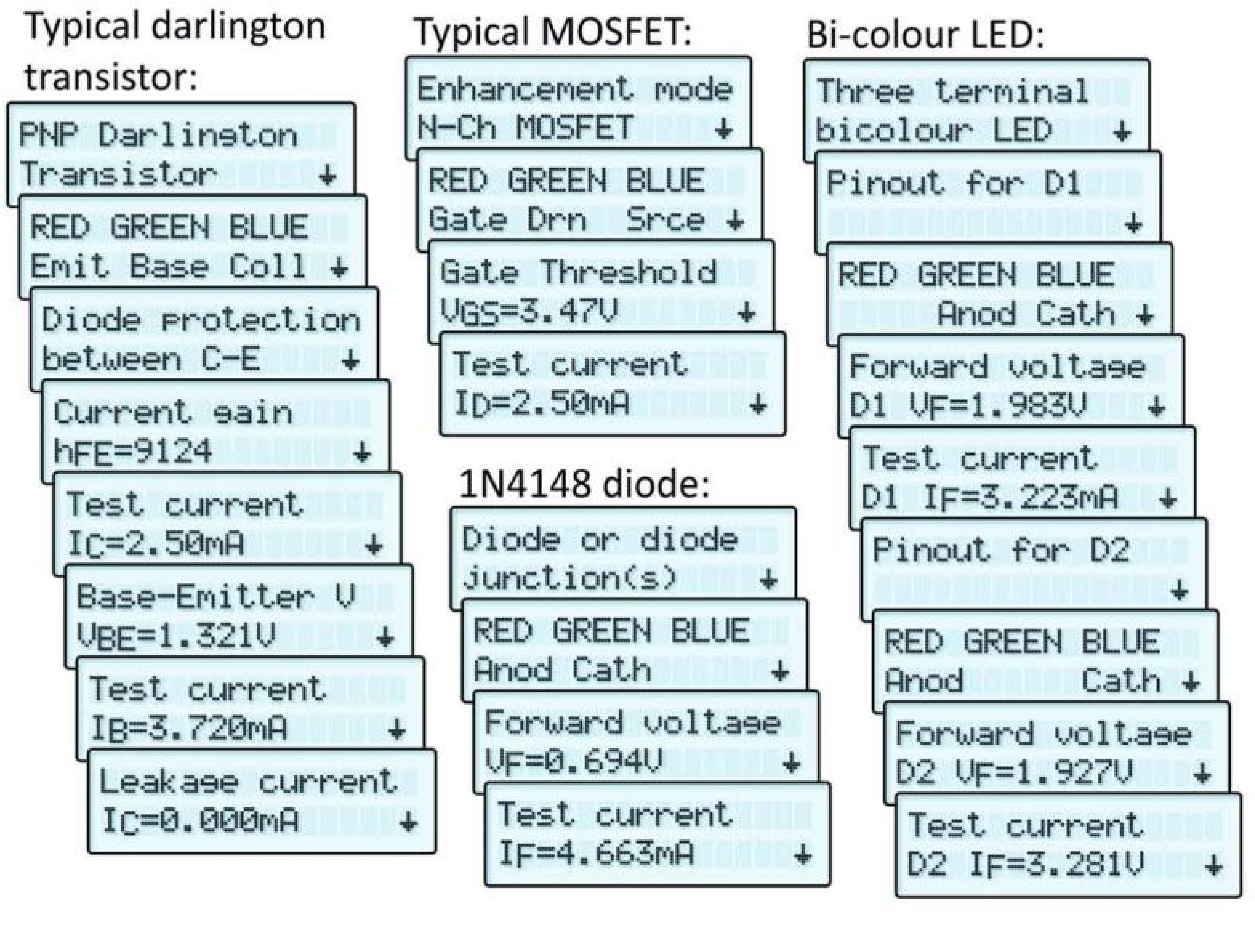
Example Screenshots



Typical darlington transistor:

```
PNP Darlington
Transistor      ↓
RED GREEN BLUE
Emit Base Coll ↓
Diode protection
between C-E     ↓
Current gain
hFE=9124        ↓
Test current
IC=2.50mA       ↓
Base-Emitter V
VBE=1.321V      ↓
Test current
IB=3.720mA      ↓
Leakage current
IC=0.000mA      ↓
```

Typical MOSFET:

```
Enhancement mode
N-Ch MOSFET     ↓
RED GREEN BLUE
Gate Drn  Srce ↓
Gate Threshold
VGS=3.47V       ↓
Test current
ID=2.50mA       ↓
```

1N4148 diode:

```
Diode or diode
junction(s)     ↓
RED GREEN BLUE
Anod Cath       ↓
Forward voltage
VF=0.694V       ↓
Test current
IF=4.663mA      ↓
```

Bi-colour LED:

```
Three terminal
bicolour LED    ↓
Pinout for D1
                ↓
RED GREEN BLUE
     Anod Cath ↓
Forward voltage
D1 VF=1.983V    ↓
Test current
D1 IF=3.223mA   ↓
Pinout for D2
                ↓
RED GREEN BLUE
Anod      Cath ↓
Forward voltage
D2 VF=1.927V    ↓
Test current
D2 IF=3.281V    ↓
```

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